Considerations for the Effective Management of Atlantic Scallops

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ABSTRACT

Sinclair, M., R.K. Mohn, G. Robert, and D.L. Roddick. 1985. Considerations for the effective management of Atlantic scallops. Can. Tech. Rep. Fish. Aquat. Sci. 1382: vii + 113 p.

This briefing document summarizes information relative to the definition of a scallop management plan for the Scotia-Fundy Region. First, the scallop fisheries within the Region are described. Second, the fisheries management initiatives that have already been implemented are reviewed. Third, the biology of sea scallops (Placopecten magellanicus) as it relates to both recruitment and growth overfishing is summarized. Given certain

features of the biology of scallops, and the present state of the art of stock assessments for this species, management options (from a biological point of view) are briefly summarized.

RÉSUMÉ

Sinclair, M., R.K. Mohn, G. Robert, and D.L. Roddick. 1985. Considerations for the effective management of Atlantic scallops. Can. Tech. Rep. Fish. Aquat. Sci. 1382: vii + 113 p.

Ce document résume les connaissances se rapportant à la définition d'un plan de gestion pour les pétoncles dans la région Scotia-Fundy. Premièrement, on décrit les différentes pêcheries de la Région. Deuxièmement, on fait un revue des mesures de gestion de la pêche aux pétoncles déjà en place. En dernier lieu, on présente certains facteurs biologiques du pétoncle (Placopecten magellanicus) par rapport à la surexploitation tant du point de vue de la croissance que du recrutement. Après avoir considéré certaines caractéristiques de la biologie du pétoncle et des techniques mises au point dans l'évaluation de ces stocks, on décrit brièvement quelques mesures de gestion (d'un point de vue biologique).

INTRODUCTION

This briefing document has been written at the request of J.E. Stewart, Director of the Fisheries Research Branch, Scotia-Fundy Region, to provide information relevant to the definition of a scallop management plan. First, the development of the Scotia-Fundy Region scallop fishery is described. Second, the fisheries management initiatives that have already been implemented are reviewed. Third, the biology of scallops as it relates to both recruitment and growth overfishing is summarized. Given certain features of the biology of scallops, and the present state of the art of stock assessments for this species, management options (from a biological point of view) are briefly summarized.

THE SCALLOP FISHERY OF THE SCOTIA-FUNDY REGION

This section is divided into two parts. First, the development of the Georges Bank fishery is illustrated. Second, the Bay of Fundy fishery is treated.

THE GEORGES BANK FISHERY

The scallop landings from 5Ze by Canada and the United States from 1953 to 1983 are shown in Table 1 and Figure 1. The geographic distribution of the scallop catch in NAFO SA 5 by Canadian and United States vessels from 1957 to 1981 in 3-yr intervals is shown in Figures 2a to 2h. Catch by 10 min^2 is not yet available for the United States since 1981. The growth of the Canadian Georges Bank scallop fleet is shown in Table 2.

THE BAY OF FUNDY FISHERY

A small but long-standing scallop fishery off the Charlotte Co. coast of southwest New Brunswick was reported in 1889 by W.F. Ganong. "In New Brunswick a schooner occasionally brings a quantity (of scallops) to St. John from L'Etang Harbour or Mace's Bay where they are taken by dredges...the quantity sold is estimated to be about 200 bushels annually" (Ganong 1889). Until 1920 Charlotte Co. was the only area within the Bay of Fundy that had a fairly regular fishery for scallops. With the discovery of scallop beds in Annapolis Basin in 1920, the Digby fishery was begun and rapidly expanded into the Bay of Fundy. Over the past 30 yr landings from Nova Scotia have dominated the overall Bay of Fundy scallop fishery. First the dominant Nova Scotia Bay of Fundy fishery is described, then the New Brunswick (predominantly Grand Manan) fishery is dealt with.

Nova Scotia side

Scallop beds off Digby, N.S., have been exploited on a commercial basis since the 1920's. The landings and the traditional fishing areas are shown respectively in Table 3 and Figure 3.

With the development of the offshore scallop fleet after World War II, Georges Bank accounted for the great majority of Canada's annual scallop catches. The Bay of Fundy fleet now contributes a relatively small proportion of overall scallop production, but it is still of considerable importance to the Scotia-Fundy Region.

On occasion, the Bay of Fundy scallop fleet has supplemented its catch by fishing offshore banks (e.g. German and Lurcher) and the approaches to the Bay of Fundy. Lately, this has occurred to the extent that nearly half of the fleet's landings originate from outside their traditional fishing grounds in the Bay as shown in Figure 3.

In 1973, a freeze on issuing new licences was instituted and approximately 60 limited-entry licenses were established. Subsequently, additional licenses have been approved, bringing the total number of licenses up to slightly less than 100. There is also a trend toward larger vessels when replacement time comes, up to the maximum (19.79 m) length overall (LOA) allowed. A little over half the fleet has been replaced since 1970. Even though the prime activity of these vessels is scallop fishing, about 80 percent hold one or more licenses for other fisheries, especially groundfish. The Bay of Fundy scallop fleet is based mainly in Digby Co., N.S., with additional home ports located in Annapolis, Shelburne, and Yarmouth Co., N.S., and Charlotte Co., N.B.

A Bay of Fundy scallop license entitles the holder to drag for scallops in the Bay of Fundy and other areas of NAFO 4X and, under special trip permit, in Subdivision 5Ze. An additional number of "inshore" licenses may potentially contribute to Bay of Fundy scallop landings; but their input is fairly small. Table 4 sums up the number of both types of scallop licenses landing scallop meats along the coast of southwest Nova Scotia for vessels under 19.8 m LOA.

The record high landings (over 1,000 t of scallop meats from District 38 alone in 1981) originated from the Bay of Fundy component of the scallop fleet, particularly from vessels between 14 and 19.8 m LOA. Inshore vessels from these districts landed relatively negligible quantities. The long-term average catch (1950 to 1977) for this area is 325 t of scallop meats (Jamieson et al. 1980). Rough calculations indicate that recent catch per vessel inside the 6-mi fishing zone in the Digby area, despite extremely high overall landings, is near long-term low levels (Robert et al. 1984a).

New Brunswick side

The fishery in the Grand Manan area has been recently described in some detail (Robert et al. 1984b; Dadswell et al. 1984). The vast majority of the Grand Manan scallop fleet are boats of the Cape Island design. They average 14 m LOA and are crewed by two or three men. They can readily change from one type of fishery to another; for example from lobster fishing, to scallop fishing, to fish dragging. When fishing scallops, they usually tow 4- to 6-gang Digby-type drags from the starboard side, where dumping boards are installed.

Scallop fishing is restricted to license holders. Grand Manan vessels carry a Bay of Fundy scallop license (Table 5) or an inshore (7-mi) New Brunswick license (Table 6). A freeze has been imposed on the issuing of Bay of Fundy licenses since 1973. The majority of Bay of Fundy licensed vessels operate from Digby, N.S., but a few operate from New Brunswick, especially Grand Manan. The number of New Brunswick-based Bay of Fundy licenses has remained fairly constant during the past 5 yr. These licenses are commonly bought and sold from one side of the Bay to the other, and slight shifts take place in the Bay of Fundy scallop fleet. In 1982, the Grand Manan area had 16 Bay of Fundy scallop licenses, in comparison with a total of 20 in previous years.

Inshore, or 7-mi, New Brunswick licenses entitle the holder to fish for scallops within 7 naut mi of the New Brunswick coast in the Bay of Fundy and, since 1982, within the area defined as Lobster District 2 off Grand Manan (Fig. 4). The number of inshore licenses fluctuates and has doubled from 1980 to 1981 to remain at this high level in 1982 (Table 6).

Combined (inshore and offshore) landings from 1960 onward for the New Brunswick Bay of Fundy coast is shown in Table 7. Catches have climbed sharply since 1980. Grand Manan Island (District 50) landings hit record highs in 1981 (Fig. 5), followed distantly by Deer Island, Campobello Island, and Passamaquoddy Bay. Landings for 1982 remained high, although at a lower level. Long-term (20 yr) average annual landings for these areas are only 8.6 t (1960-1979), but jump to 58.7 t when the time period 1963 to 1982 is considered. Since small, inshore vessels land most of the catch, and most of the fishing done by these small (<14 m LOA; $\leq$ 25.5 GT) vessels is in the vicinity of landing ports, landing statistics reflect, in a coarse way, the state of local scallop beds.

HISTORY OF THE REGULATION OF SCALLOP FISHERIES IN THE SCOTIA-FUNDY REGION

Regulations for scallop fishing were first introduced in 1918 to reduce the fishing pressure on the scallop beds in Mahone Bay and Chester Basin, N.S., which at that time were the

only scallop beds that supported a large commercial fishery [over 250 licenses in 1919 (Anonymous 1920)].

These regulations included licenses with a $1 fee, a closed season (June 1 to September 15), and a minimum size (4 inch diameter shell). It is interesting to note that each of these three types of regulations (licensing, size restrictions, and effort limitation) are still in use today.

There was another, less-successful regulation introduced in 1920 in a further attempt to help the Mahone Bay and Chester Basin fishery. This was to prohibit the export of scallops from Nova Scotia. Although this regulation did help reduce the fishing pressure in the existing scallop fisheries by reducing the market and thus the price, it also stopped the development of other lucrative beds such as those in Digby. As a result the regulations that were instituted on May 22, 1920, were revoked on December 9, 1920. At that time, however, a special short season for Mahone Bay of December 15 to January 20 was introduced. Also, the throwing overboard of the waste portions of the scallop on the scallop beds, and the soaking of the meats in freshwater, were prohibited at the same time.

The charges in the regulations, as published in the Canada Gazette, are listed in Tables 8a, b, and c.

OVERFISHING

A useful distinction has been made between two types of overfishing, so-called "recruitment overfishing" and "growth overfishing." The first concept involves the self-reproducing capacity of the population under exploitation. Clearly, fishing mortality should not be so extreme that it limits the ability of the mature spawning population to effectively provide adequate future recruitment. This fragility of populations to exploitation is perhaps the least understood area of fisheries biology. It should be noted, however, that recruitment overfishing does occur for some species and that its prevention must be carefully considered in a management plan. Since quantitative criteria to monitor this type of overfishing are generally lacking, simple qualitative guidelines may have to suffice. The second concept, growth overfishing, is better understood but less critical. Given what is known about the growth rates, the mortality rates at age, and the effective selectivity of the fishery for each age, it is straightforward to estimate the level of fishing effort and the total catch that will maximize the yield in weight (or dollars if other economic information is available) from a given "spatfall" or recruitment level. The various forms of the analytical yield model make these predictions straightforward. The danger is in the seductiveness of a quantitative result from a model. The answer is only as good as the basic assumptions underlying the model and the data used. For example, the analytical yield model will

generate the same advice on an optimal fishing mortality whether or not recruitment overfishing is occurring. Yet, a manager should probably modify the fishing strategy generated from the model in a situation when recruitment failure is expected. In this section those aspects of scallop biology of relevance to fisheries management are summarized under the rubric of the two types of potential overfishing.

CONSIDERATIONS RELATIVE TO RECRUITMENT OVERFISHING

The existence of relatively discrete, self-sustaining stocks has been generally accepted for the mobile, commercially exploited fish species, but has not always been accepted for the more sedentary benthic invertebrates. Recruitment to a given geographical area is assumed to be derived from surrounding contiguous areas as a function of larval drift in relation to the residual circulation. This concept of a distant source of recruitment is drawn from the benthic ecology literature, which hypothesizes that the adaptive function of the larval phase of the life cycle of relatively sedentary species is dispersion itself. For scallop species (Placopecten), however, the extent of larval drift is purely speculative, there being no field studies of the larval distributions. The duration of the larval phase, as well as the daily and ontogenetic (developmental) behaviour patterns, are not well understood.

This assumption, that scallop aggregations may not as a rule be self-sustaining, has implications on fisheries management strategies. If appropriate, then the managers and the industry can ignore the threat of recruitment overfishing, at least for any given fishery. Their attention can be focussed instead on preventing growth overfishing. By assuming, often unstated, that self-sustaining stocks of scallops may not exist, biologists are thus implicitly passing on a specific message. In the development of a management plan it is incumbent on the biologists to spell out this assumption in very clear terms, as well as to provide the factual base backing it up. That is the aim of this component of the scallop briefing document.

There are two approaches to the question of the source of recruitment to exploited scallop aggregations, a deductive and an inductive approach. In the former approach lengthy field studies on spawning, larval distributions, and spat settlement are required. Answering this question by field studies is a major focus of the ongoing scallop research program of the Fisheries Research Branch, Scotia-Fundy Region, which was initiated in 1983. Reproducible results and firm conclusions cannot be expected for several years. The inductive approach has, however, some merit; and it leads to immediate conclusions, albeit more speculative ones. This latter approach is taken here.

Three scallop species of commercial importance in the North Atlantic (Chlamys opercularis, Pecten maximus, and Placopecten magellanicus) have been selected for comparative study. First, several simple features of their general biology are summarized (geographic distribution, persistence of aggregations in specific locations, relative biomass of aggregations, and spawning times). The observed patterns are then discussed in relation to some simple features of the oceanography (residual circulation, tidal circulation, tidally induced stratification features). Finally, conclusions are drawn relative to the stock question and source of recruitment assumption. The detailed information and the scientific sources used to derive this synopsis are available from the senior author.

Chlamys opercularis (queen scallop)

The various commercial fisheries for the queen scallop are shown in Figure 6, and certain biological characteristics are summarized in Table 9. Some simple observations can be drawn from the summary illustration and table. The commercial fisheries are few in number, precise in their location, and widely separated. The major aggregations, at least, have been observed and exploited in precisely the same locations for about a century. The relative biomass of the diverse aggregations, as estimated by average reported yield, varies considerably.

Spawning times are not well described for most of the fisheries. However, those that are better understood (2, 3, 5, 6, 9) show differences. For example, if the summer spawning period is considered, there is a south-to-north trend (May-June in the English Channel, June-July in the Irish Sea, and late summer in the Faroes). Differences in growth rates have also been described between areas (Broom 1976). There is no evidence of differences in age of maturity or in life span. There have been several electrophoretic studies (i.e. studies on enzyme composition of various aggregations on Chlamys opercularis (Mathers 1975; Beaumont and Gruffydd 1975; Beaumont 1982). The conclusions of these studies are that there are genetically different Chlamys stocks in the northeast Atlantic. For example, it has been concluded that there are at least four relatively genetically isolated populations around the British Isles: 1) north and west Scottish coasts; 2) the Irish Sea, 3) the Celtic Sea; and 4) the English Channel (Beaumont 1982).

Pecten maximus (coquille St. Jacques)

The various commercial fisheries for Pecten are shown in Figure 7, and certain biological characteristics are summarized in Table 10. As was the case for the queen scallop, some simple observations are of note. For this species there are many more exploited aggregations, which have been grouped under 27 geographic areas. The distributions are in some cases

coincident with Chlamys but tend to be more inshore. Again, the geographic locations of the exploited aggregations are very precise and in some cases they have been fished continuously for over 200 yr. The relative biomass of these persistent aggregations varies considerably (Table 10). Spawning times, although not well documented for each area, show some geographical variation. In the southern aggregations (1 to 9), spawning occurs during the summer months. In the Irish Sea and along the west coast of Ireland, however, spring and late-summer spawning are reported to be discontinuous (17, 18, 25). Growth differences between aggregations are also reported (Franklin and Pickett 1980; Gibson 1956; Mason et al. 1980). No electrophoretic studies on enzyme differences between aggregations have been reported.

Placopecten magellanicus

The various commercial fisheries for Placopecten are shown in Figure 8, and certain biological characteristics are summarized in Table 11. Again, the commercially exploited aggregations are observed in precise geographic locations which are widely separated. The aggregations are persistent in time, the Annapolis Basin beds being known for over 350 yr. The relative biomass levels (as estimated by average yield) vary considerably between locations, for example from tens of thousands of tons/year from the northeast peak of Georges Bank (15) to hundreds of tons/year in the Pictou Island area (8). Timing of spawning is relatively similar between aggregations (predominantly early autumn), but growth differences between areas have been reported. Unpublished results of electrophoretic studies (L. Zouros, pers. comm.[1]) indicate that there are surprisingly small differences in enzyme characteristics between aggregations.

Oceanographic considerations

The duration of the larval phase of the three scallop species under consideration is about 2 mo. At the end of this pelagic phase the larvae settle on an appropriate benthic substrate and metamorphose into juvenile scallops. The larvae are very small during this phase, growing from 70 µm to 300 µm during the 2 mo. They have some capability for vertical movement in the water column; but the extent of such movement, the existence of endogenous rhythms, and any changes in swimming behaviour with age are not known. Given the small size of the larvae, the strength of residual currents in relation to possible larval swimming speeds, and the duration of the larval

[1]Dr. L. Zouros, Professor, Biology Department, Dalhousie University, Halifax, N.S. B3H 4J1

phase, it has been concluded that the larvae are widely dispersed. However, the persistent, widely separated, pattern of the scallop aggregations of characteristic biomasses shown in Figures 6, 7, and 8 suggest in contrast that the pattern is a self-sustaining one.

It is of interest to consider some characteristics of the physical oceanography of the various scallop aggregations. Many of the aggregations are coincident with tidally induced features. The predicted location of zones of water column transition from stratified to well-mixed conditions are shown in Figures 9, 10, and 11. Chlamys Aggregations 1, 2, 3, 4, 5, 6, and 7 shown in Figure 6 are approximately coincident with such tidally induced physical transition zones shown in Figure 9. Some but not all of the Pecten aggregations are also coincident with such features (Aggregations 4, 5, 6, 7, 12, 13, 14, 15, 17, 18, 22, 24, 27, 28). Placopecten Aggregations 7 and 8 (Fig. 8) are coincident with the tidally induced stratification transition zones shown in Figure 11; and Aggregations 11, 13, 15, and 17 (Fig. 8) with the similar physical features shown in Figure 10. In sum, many of the commercially important scallop aggregations are approximately coincident with tidally induced water column features. The physical oceanography of such areas is not well understood but is under active study. In such areas the tidal circulation is usually an order of magnitude greater than the residual circulation. It may well be that the larval populations can ignore the residual circulation but use the stronger tidal circulation to maintain their distribution in relatively fixed geographical areas. Vertical migration of the larvae in relation to the strong gradients in the tidal circulation intuitively provides a mechanism by which the larvae could limit the extent of their dispersal.

Several of the scallop aggregations that are not associated with strong tidal circulations (that may provide a mechanism for "larval retention") are located in geographic areas of persistent gyres (Aggregations 5 and 6 in Figure 8) or in semi-enclosed bays characterized by two-layer circulation (Aggregations 25 and 26 in Figure 7). Interestingly, herring larvae have been shown to be retained in a bay within Area 25 (Grainger 1980) (Fig. 7). In sum, for many of the scallop aggregations there are physical features that may permit the larvae to maintain a distribution independent of the residual circulation.

The stock question

At present, the question of whether scallop aggregations are self-sustaining cannot be conclusively resolved. Nevertheless, the simple observations of the persistence of widely separated aggregations of scallops of characteristic absolute abundances in precise geographic locations strongly implies that many of the aggregations are self-sustaining. The

patterns are difficult to rationalize in relation to large-scale residual circulation patterns, but many of the aggregations are coincident with either tidally induced physical oceanographic features, relatively persistent gyres, or areas characterized by two-layer circulations. The growth differences and spawning time differences between aggregations within each species do not in themselves indicate that there are separate biological stocks, but the results are consistent with such a conclusion. The lack of enzymatic differences between aggregations of Placopecten suggests that there may be sufficient exchange between areas to prevent genetic differentiation. It does not, however, negate the interpretation that, on the ecological time frame of interest to fisheries management, many of the aggregations are, for practical purposes, self-sustaining.

How, then, do these generalizations concerning the existence of self-sustaining populations of scallops relate to the concept of recruitment overfishing? The comparative study leads us to tentatively conclude that many of the scallop aggregations that support commercial fisheries are self-sustaining populations. This implies that if all the scallops are fished out in any given area, future recruitment should not be expected from contiguous areas within the time frame of interest to fisheries management. Thus, some minimum spawning biomass must be maintained in each fishery area to ensure long-term harvesting potential. Accepting these conclusions, the critical question then arises of whether present fishing patterns guarantee a minimum spawning biomass. The evidence is mixed. There is some evidence that recruitment overfishing has occurred in scallop fisheries. Mahone Bay supported a large scallop fishery in the Maritimes early in this century (up to approximately 250 scallop licenses and catches on the order of 60 t of meats per year). Overexploitation was recognized in the early 1920's and strict conservation measures imposed (see "History of Regulation of Scallop Fisheries in the Scotia-Fundy Region" section). The scallop aggregations, however, have not recovered to the original 1910's levels. In contrast to the Mahone Bay scallop aggregations, the major Placopecten fisheries (northeast Georges Bank and the "Digby" fisheries, for example) have shown considerable resilience to heavy exploitation. This suggests that the minimum spawning biomass required for successful recruitment is being maintained, either by sufficient areas of refugium (due perhaps to rocky areas unsuitable for dragging) or economic self-limitation (at sufficiently low densities, fishing becomes unprofitable). What constitutes a minimum spawning biomass for successful recruitment, or the extent of refugia in the various scallop aggregations, is not known. These questions are being addressed in present research programs, but they are difficult to resolve and the answers may not be forthcoming in the short term.

In sum, a conservative assumption is that the various fishing areas are self-sustaining, and thus that a viable spawning stock must be maintained. Since this minimum level

cannot yet be defined for any specific fishery, arbitrary measures should be incorporated into a management plan to prevent recruitment overfishing.

CONSIDERATIONS RELATIVE TO GROWTH OVERFISHING

This section is divided into two components. First, a brief introduction to analytical yield models (which provide a basis to quantify the growth overfishing concept) is provided. Second, two categories of fisheries regulations used to optimize yield per recruit, and thus prevent growth overfishing, are considered. These two categories of regulation (age selection and effort limitation) are elaborated on, using the northeast Georges Bank fishery as an example.

The exploited fish population analytical yield model

This model (Baranov 1918) and its derivations (Thompson and Bell 1934; Beverton and Holt 1957), which allow estimation of yield as a function of fishing effort and gear selectivity-at-age, assume that the exploited populations are in a stable age distribution. The models consider the catch obtained from one year class, or cohort, throughout its life. It follows that under steady-state conditions (i.e. stable age distribution) the annual catch from the overall population under a given fishing strategy equals the catch that can be taken from a single cohort throughout its life under the same strategy. This may be called the principle of equivalence. Thus annual yield at constant recruitment can be maximized by maximizing the following relationship for a single cohort,

$$Y = \int_{t=1}^{n} F_t \cdot N_t \cdot W_t \cdot dt$$

in which Y is the annual yield, F_t is the instantaneous fishing mortality, N_t is the abundance of the cohort-at-age t, and W_t is the fish weight at age t (the meat weight-at-age of Georges Bank scallops is shown in Figure 12). Beverton and Holt (1957) identified separately the age at recruitment to the population and the age of availability of the cohort to the fishing gear. In practical terms this allowed one to evaluate the effect of varying fishing gear selectivity, as well as fishing effort, on the sustainable yield. In the original formulation, as well as in most of the subsequent applications, N_t is a simple function involving constant recruitment, constant natural mortality-at-age, and variable fishing mortality-at-age. W_t was described empirically (Thompson and Bell 1934) or by using an appropriate growth equation (Beverton and Holt 1957). In the yield per recruit derivation of the model (Beverton and Holt 1957), yield per recruit (again at a constant recruitment level and thus a stable age

distribution) can be predicted as a function of various fishing strategies, involving both the total fishing effort (i.e. fishing mortality, F) and the manner in which it is distributed over ages. It is this latter derivation (yield per recruit) that is routinely used in fish stock assessments. The fishing mortality that predicts either the maximum yield (F_{max}) or an alternate yield for a different management strategy, such as $F_{0.1}$ yield (Gulland 1968; Gulland and Boerema 1973) for a given gear selectivity-at-age, is of interest to management.

To generate biological advice on catch quotas for a fish or invertebrate stock on a yearly basis, assessment biologists apply the fishing mortalities-at-age, which predict yield at F_{max} or yield at $F_{0.1}$, to the present stock abundance-at-age estimates derived from cohort analysis. The summation of the calculated removals-at-age times the weights-at-age provide an estimate of the catch quota [the total allowable catch (TAC)] under a chosen management strategy (such as yield at F_{max} or at $F_{0.1}$). Alternatively the effort can be regulated directly to generate a target fishing mortality in relation to the model predictions.

There are two approaches to using the analytical yield model to regulate a fishery with the aim of optimizing yield or value. The first is to control the selectivity-at-age of the fishery. In other words, to regulate the sizes or ages of scallops that can be harvested (by such mechanisms as minimum ring size restrictions, minimum meat weights, or meat count targets). The second approach is to control the overall effort of the fishery, either directly by effort limitation or indirectly by catch limitations. The two approaches are, of course, not mutually exclusive. For clarity, the two approaches are first discussed separately and subsequently in combination.

Three variants of regulating the selectivity-at-age (or size) characteristics of the fishery are already in place or under consideration in the Gulf of Maine/Scotian Shelf area. The retention characteristics of the gear can be regulated. Smolowitz (1979) summarized studies on the selectivity of various ring sizes in the New Bedford scallop dredge and their efficiency. The gear with 75-mm rings, for example, had a 50% retention for 70- to 80-mm animals; and all animals above approximately 110 mm were retained. The regulation of ring size, however, is not a good escapement mechanism for small animals as the dredge fills with larger animals and other materials. The actual selectivity-at-age of the fishery, when only the fishing gear is regulated, can be better estimated from a retrospective analysis of the northeast Georges Bank fishery itself. The selectivity-at-age for such an approach is approximated by the 1981 fishery when the other regulations were relaxed. The approximation of the selectivity pattern with no meat count regulation is shown in Table 12 and Figure 12 (PR_{81}). The fishery during 1981 using 75 mm rings did not show 50 percent retention for 70-80 mm animals (age 3 scallops in

Fig. 12). Maximum yield per recruit, when only the gear is regulated (i.e. the 1981 selectivity), is 11.8 g and yield per recruit at $F_{0.1}$ is 11.3 g.

Modifications of this general approach include harvesting with either a minimum meat weight or an average minimum weight (blended meat count expressed here as number of meats per 500 g). Under the former regulation the objective is to protect all animals under a given size (a size differing from that retained by the gear itself). The minimum meat weight is considered impractical to apply in actual fishing practices and is not further analysed. Under a blended meat count regulatory approach, the average size of the individual scallops in the catch is specified, but the catch is composed of animals above and below the target average size. Approximations of the selectivity-at-age vectors for three different blended meat counts are also shown in Table 12, as are the yields at F_{max} and at $F_{0.1}$. Note that the fishing mortalities (both at the first fully selected age, i.e. unity in the selectivity vector, and the average over all ages, $\bar{F}$) to achieve the target yields are also shown.

The changes in fishery selectivity associated with respectively - a relaxed meat count (1981), a 39 meat count (1983 situation), a 26 meat count, and a 17 meat count - are shown in Figure 12. Two things are to be noted. First, the maximum selectivity values are for ages 4, 5, and 6, an age span relatively low on the growth curve. Second, the differences between the selectivity curves for the first three meat count targets are slight. Not surprisingly, the predicted increase in yield per recruit in moving from a relaxed meat count to a 26 meat count is small (from 11.8 g to 13.4 g). In order to benefit from the full growth potential of Placopecten, a shift toward exploiting older ages, those ages in the central portion of the growth curve shown in Figure 12, is required (i.e. a fishing strategy targeted on 5-, 6-, and 7-yr olds). This option is shown as PR_{17} in Figure 12 and Option B in Table 12. The yield per recruit fishing under this option is considerably higher (18.2 g).

In sum it is noted that only marginal increases in yield can be generated by shifting the selectivity curve around a maximum at age 5 (which is in fact the present fishing pattern). Such an approach dissipates much of the biological growth potential and in addition results in a low egg production per recruit. To more fully utilize the growth potential of scallops 5-, 6-, and 7-yr olds should make up most of the catch.

The second approach to using the analytical yield model (in relation to the prevention or minimization of growth overfishing) is the regulation of fishing mortality itself. The setting of catch limitations is one option available. The $F_{0.1}$ and F_{max} values for the range of selectivity vectors shown in Table 12 vary between 0.46 and 1.09. Using an

appropriate combination of exploitation level (such as $F_{0.1}$ or F_{max}) and a given selectivity strategy, annual catch limitations can routinely be calculated in an analytical assessment. There are several logical steps if such an approach is to be implemented. First, the management units in the Scotia-Fundy Region have to be defined. The management units should be defined in relation to the population structure of scallops (Fig. 8). As noted above, the degree to which the various scallop aggregations are self-sustaining is not known. The prudent assumption taken here is that many of the aggregations are, for practical purposes, self-sustaining populations. The overall area could thus be divided into several management units from a biological point of view (based on the distributions shown in Figure 8). Fisheries operational factors and other management considerations may, however, demand a different set of management units. For this part of the briefing document we will assume that the northeast Georges Bank aggregation is a separate management unit.

The second step in the analytical assessment is the estimation of population abundance-at-age within the management unit at the beginning of each year. This is done using a sequential population analysis model (or cohort analysis). Optimally three sets of information are required: 1) age composition of the catch for several years; 2) indices of CPUE and effort on an annual basis; and 3) research vessel survey estimates of relative abundance for several years. An example of research into cohort analysis for northeast Georges Bank scallops was provided by Mohn et al. (1984).

The third step in the assessment is the calculation of the appropriate fishing mortality in relation to the management strategy (such as $F_{0.1}$ or F_{max}) using a variant of the analytical yield model described above.

The fourth and final step is the application of the chosen fishing mortality value to the selectivity-at-age vector of the fishery. The resultant fishing mortality vector applied to the estimated population numbers-at-age from the cohort analysis indicates how many scallops at each age can be taken. These numbers, multiplied by the average weights-at-age and then summed, provide the catch limit for the coming fishing year. This procedure is illustrated in table form below (in this example the Option B selectivity pattern, a $F_{0.1}$ level effort, and the 1983 estimated population numbers-at-age for the northern edge and northeast peak of Georges Bank are used).

	A	B	C	D	E	
Age	F	Selectivity vector	Population numbers (10^6)	Average weight (g)	Product (AxBxCxD) (t)	Percent by weight of catch at each age
5	0.59	0.30	126	19.1	426	17
6	0.59	0.60	67	26.7	633	26
7	0.59	1.00	37	32.9	718	29
8	0.59	0.60	23	37.6	306	12
9	0.59	0.40	21	41.1	204	8
10	0.59	0.20	15	43.6	77	3
11	0.59	0.11	9	45.4	27	1
12	0.59	0.15	7	46.7	29	1
13+	0.59	0.28	8	47.5	63	3
					TAC = 2,483	100%

The northeast Georges Bank fishery has been regulated, in relation to the growth overfishing concept, by the first approach (i.e. the selectivity-at-age characteristics of the fishery by gear regulations and blended meat counts). The effort used, and thus the resultant fishing mortality, has been allowed to vary. The estimated fishing mortality during the past 10 yr is shown in Figure 13. It has exceeded both $F_{0.1}$ and F_{max} defined at the 39 meat count fishing pattern (PR_{83}) from 1972 to the present. The loss of yield that has occurred by fishing at this high level is shown in Figure 14. The accumulated yield from 1972 to 1983 from the actual fishery was close to 96,000 t of meats. By fishing at $F_{0.1}$ with the same selectivity-at-age the accumulated yield would have been 25 percent higher. Note that this estimate is the loss that would have occurred based on the actual historical recruitment. It is not known to what degree parental stock affects recruitment; but it stands to reason that beneath a certain size (presently undetermined) recruitment would be adversely affected. The relative egg production under the 1983 fishing strategy (F) is compared to $F_{0.1}$ fishing in Table 13 and Figure 15. At $F_{0.1}$ (PR_{83}) about 79 percent of the ovary biomass is maintained relative to the unfished situation. At present exploitation levels ($F \geq 1$) less than 17 percent of the ovary biomass is present.

In sum, analysis of the second approach to preventing growth overfishing (i.e. restricting the level of fishing effort to some target level such as $F_{0.1}$ or F_{max} at a given fishing selectivity pattern) indicates that accumulated yield since 1972 at actual recruitment levels would have been about 25 percent higher and egg production would also have been significantly greater if effort had been lower (i.e. at $F_{0.1}$ level).

In concluding this part of the briefing document the two approaches to preventing growth overfishing (control of respectively, the selectivity-at-age of the fishery and the overall level of exploitation) are discussed in combination. With both the selectivity pattern shifted toward 6- and 7-yr olds, and the fishing effort reduced to a $F_{0.1}$ level, substantial increases in yield, catch per unit of effort, and egg production can be realized.

The yield that could have been taken from the actual recruitment that occurred on the northern edge and northeast peak of Georges Bank is shown in Figure 14 (i.e. yield at $F_{\text{Option B}}$) (valid, provided that a different exploitation regime would not have affected recruitment patterns). In 1972 and 1973 the yield would have been lower than that actually taken ("historical" yield in Figure 14). In subsequent years, however, the catches would have been increasingly larger. The accumulated difference between actual catches and $F_{\text{Option B}}$ catches is 55,400 t of meats. The biologically more-optimal fishing strategy would have yielded 58 percent more scallop landings from the actual recruitment, most of this increase occurring in the more recent years.

This is considered to be a conservative estimate with respect at least to the loss in yield if, in general terms, one expects on average some increase in recruitment with sustained higher egg production. With current fishing practices (PR_{81} or PR_{83}, and fishing mortality in excess of unity) less than 17 percent of the egg production per recruit is realized (relative to the unfished situation). With the Option B fishing strategy over 29 percent of the egg production would be produced, a significant increase.

Finally, the catch-rates could have been higher. With the present fishing strategy, yield per unit of fishing mortality (or an index of CPUE) is about 12.5. With Option B, fishing at $F_{0.1}$, yield per unit of fishing mortality is close to 28.9, a more than twofold increase (see Table 12).

In sum, the present fishing strategy in the Scotia-Fundy Region, as shown by the eastern Georges Bank example, far from optimizes either yield in weight or landed value. The scallops are being caught at too young an age, using too much effort.

MANAGEMENT OPTIONS FROM A BIOLOGICAL POINT OF VIEW

The present status of the several scallop stocks which are fished from Scotia-Fundy ports was not specifically summarized in the previous sections, even though the relevant information has been introduced. A brief synopsis of the present situation is provided prior to a discussion of management options.

The northern edge and northeast peak of Georges Bank scallop stock has been assessed using the standard analytical methodology that was developed initially for fish populations. The application of this methodology is the focus of ongoing research. Thus, estimates of absolute abundance and fishing mortality are available for the years following 1972. The stock abundance is currently at the lowest level within this time period (1972 to 1983). Spawning stock levels as well as the size of the recently recruited year classes (up to 1983) are very low. The present combined fishing strategy of Canada and the United States results in very low egg production per recruit (less than 17 percent of that generated during the unfished state). The recent exploitation levels on ages 4-, 5-, and 6-yr old scallops are shown in Figure 13. These levels markedly exceed both F_{max} and $F_{0.1}$. An F level of 1.2, assuming that natural mortality at these ages is 0.1, translates into an annual mortality rate of 73 percent. This mortality is being directed at scallops at their initial stages of maturation (see Figure 12). In sum, the stock status is at a critically low level and the present management regime does not promote stock recovery. The free-for-all attitude and regulatory vacuum that has prevailed since extension of jurisdiction, and thus the definition of a disputed zone on eastern Georges Bank, has no doubt contributed to the creation of the present bleak stock status. It is not, however, the sole reason because the other considerably smaller stocks in undisputed Canadian waters are also in a somewhat depressed state.

A rigorous analysis of absolute abundance and fishing mortality levels cannot at present be made for the other scallop fishing areas. Some qualitative statements can, however, be made. The Mahone Bay-Chester Basin fishery (which sustained catches in excess of 60 t of meats) was seriously depleted in the early 1920's and has never fully recovered. Even though the landings on the Nova Scotia side of the Bay of Fundy are at record high levels, the catch-rates for the traditional "Digby" fishery are at historically low levels. The recent high catches are a result of expansion of the Digby fishery to the approaches to the Bay of Fundy and to nearby Scotian Shelf stocks. After a rapid increase in landings on the New Brunswick side of the Bay of Fundy (predominantly in the Grand Manan area) peaking in 1981, the landings and the catch-rates have stabilized at lower levels. Much less is known about the status of the scallop stocks on the Scotian Shelf banks. Except for those areas where our information is lacking, it is safe to conclude that the overall status of the scallop resources exploited from Scotia-Fundy Region ports is severely depleted. The present management framework and regulation history has not led to healthy stock status.

What, then, are the options from a biological point of view that will both promote stock rebuilding and optimize yield (and presumably value) from whatever recruitment actually occurs in the short term? In the discussion of options the Georges Bank

scallop fishery is focussed on. The conclusions should be applicable to other areas.

As outlined in the "Overfishing" section, there are two approaches that can be taken to optimize yield per recruit from age-structured populations. The approaches can of course be combined. Either the selectivity-at-age pattern of the fishery can be adjusted toward older ages, or the exploitation level (or the effort) can be reduced, or both. Of these two approaches the former is more effective in increasing yield per recruit (Table 12). Following the present strategy (1983 selectivity pattern, 39 meat count, and a high fishing mortality rate of, for example, 1.2), the yield per recruit is 11.8 g. If the effort is reduced substantially, to maximize yield (i.e. F_{max} level), the yield per recruit is 12.5 g. The long-term gain in yield is, on the average, only 6 percent. Catch-rates, however, would increase sharply by over 70 percent. In contrast, if the effort is left unchanged but the selectivity pattern is changed toward older ages (5-, 6-, and 7-yr olds, meat count 17), the increase in yield per recruit is considerably greater (55 percent). The gains that could be made by this shift in exploitation pattern were quantified by the retrospective analysis summarized in Figure 14. It is to be noted that even in this extreme example of a shift in the selectivity pattern of the fishery (39 meat count to about 17 meat count) 17 percent by weight of the catch would be 5-yr olds, and a higher percentage by numbers (see page 14 for the percent of the catch at each age).

The above analysis deals only with improving the yield from whatever recruitment occurs. It does not address the problem of recruitment overfishing or stock rebuilding. The shift in the selectivity pattern, irrespective of the level of effort would, however, markedly increase egg production (Fig. 15). In qualitative terms, maximizing yield per recruit in this fashion contributes to stock rebuilding. In contrast, the option of maintaining the present (1983) selectivity pattern but reducing effort, either directly or through catch limitations, would not substantially increase egg production (lower curve in Figure 15) even at very low exploitation levels. Thus, if the option of changing the selectivity pattern through lower meat counts is not followed, some measures should be adopted to promote stock rebuilding. The options are not numerous. They include: 1) areas closed to the fishery in order to enlarge the natural refugium; and 2) maintaining a minimum spawning stock by defining quotas above this level (the level would have to be arbitrary given the uncertainties in the form of the stock recruitment relationship).

In conclusion, for both optimizing the yield per recruit and preventing recruitment overfishing, the most effective option is to move toward exploiting older ages (i.e. toward a meat count of about 17). The gains to be realized are significant and the time frame of transition relatively short.

SUMMARY AND CONCLUSIONS

1. The histories of the scallop fisheries of importance to the Scotia-Fundy Region (Georges Bank, Nova Scotia side of Bay of Fundy, and New Brunswick side of Bay of Fundy) are described. When the Canadian fishery developed on Georges Bank in the early 1950's, the United States fishery in that area was well developed. By 1965, however, Canada dominated the overall Georges Bank scallop fishery, particularly the eastern part. This domination continued through to the 1970's. During the past 4 yr, however, the landings from 5Ze by the two countries has been approximately equal. Canadian landings since 1959 have fluctuated between 2,000 t and 13,000 t of meats annually. The changing geographic patterns of exploitation by the two fleets from 1957 to 1981 are illustrated.

2. Scallop beds off Digby, N.S., have been exploited on a commercial basis since the 1920's. The landings have fluctuated markedly. The long-term average catch (1950 to 1977) for this area is 325 t of scallop meats, about an order of magnitude lower than Canada's landings from Georges Bank. The recent landings of over 1,000 t annually are due to increased fishing in new areas, rather than an increase in the abundance of scallops in the traditional fishing area. Recent catch per vessel inside the 6-mi fishing zone in the Digby area is at long-term low levels.

3. The scallop fishery on the New Brunswick side of the Bay of Fundy, although ongoing since the 1890's, has been very small (1960 to 1979 average annual landings of 8.6 t of meats). The landings, however, increased sharply in the 1980's, particularly in the Grand Manan area (1980 to 1983 average annual landings of 340 t of meats). It is not expected that these recent high levels of landings can be sustained in the long term.

4. Regulations for scallop fishing were first introduced in 1918 to reduce fishing pressure on the scallop beds in Mahone Bay and Chester Basin, N.S., which at that time were the only scallop beds that supported a commercial fishery in the Atlantic zone. The inshore scallop fisheries of Nova Scotia and New Brunswick have been heavily regulated since that time. In contrast, the offshore Georges Bank fishery was relatively unregulated until 1973. The inshore regulations for Nova Scotia enacted in 1918 included licensing, a closed season from June 1 to September 15, and a minimum shell size of 100 mm (4 inches). In subsequent years additional restrictive regulations were added including a longer closed season (resulting in less than 2 mo fishing in some areas), prohibiting of soaking in freshwater, prohibiting of disposal of waste portions on scallop grounds, minimum ring size in rakes of 100 mm, and a gear width restriction to 5.48 m. From the late 1930's

onward many of these restrictions, however, were removed or relaxed. In 1936 the minimum ring size was decreased to 76 mm. The closed season gradually was eliminated from all areas except the 6-mi closed zone off Digby. Waste portions could be discarded on grounds after 1944. A minimum scallop size was dropped for Nova Scotia in 1953. The minimum ring size was dropped in 1963, but was reintroduced in 1976 (83 mm). In sum, there is an interesting regulation history of the inshore fisheries of initial heavy conservation measures, followed by piecemeal deregulation. The underlying justifications for many of the changes are not readily understood or documented. The opposite trend is apparent for the Georges Bank fishery. It was essentially unregulated until 1973. Since that time a minimum shell size of 57 mm (2-1/4 inches) and gradually decreasing meat counts [60 meats/lb (67 meats/500 g) in 1973 to 39 meats/500 g in 1983] have been enacted. (Note that the minimum shell size for inshore scalloping had been 100 mm in 1918.) Minimum shell size increased, however, to 95 mm (3-3/4 inches) in 1976 but was removed in 1981. The offshore fishery became limited entry in 1976. In 1977 trip and 4-mo quotas were added. The present regulations for both the inshore and offshore scallop fisheries neither promote optimal yield nor protect spawning stock. Under these regulations the scallop resource has become severely depleted. The Mahone Bay-Chester Basin scallop stock was seriously depleted in the 1920's in spite of regulations with the specific intent of scallop conservation.

5. The biology of scallops is discussed in relation to both growth overfishing and recruitment overfishing. The question of whether scallop aggregations are self-sustaining populations, or whether recruitment is derived by larval drift from contiguous upstream areas, is addressed by taking a comparative approach. Three species of commercial importance in the north Atlantic (Chlamys operecularis, Pecten maximus, and Placopecten magellanicus) were considered. Several simple features of their general biology are summarized (geographic distribution, persistence of aggregations in specific locations, relative biomass of aggregations, and spawning times). The observed patterns are discussed briefly in relation to some simple features of the oceanography (residual circulation, tidal circulation, tidally induced stratification features). The central question addressed (whether scallop aggregations are self-sustaining) cannot be conclusively resolved given present biological information. Nevertheless, the simple observations of the persistence of widely separated aggregations of scallops of characteristic absolute abundances in precise geographic locations strongly implies that many of the aggregations are self-sustaining. The patterns are difficult to rationalize in relation to large-scale residual circulation patterns, but many of the aggregations are coincident with either tidally induced

physical oceanographic features, relatively persistent gyres, or areas characterized by two-layer circulations. This comparative approach led to the tentative conclusion that many of the scallop aggregations that support commercial fisheries are self-sustaining populations. This implies that if sufficient scallops are fished out in any given discrete area, future recruitment should not be expected from contiguous areas within the time frame of interest to fisheries management. In sum, recruitment overfishing is concluded to be a potential characteristic of scallop fisheries and thus measures to prevent it by maintaining sufficient brood stock in a given area should be incorporated into a management plan.

6. The concept of growth overfishing is introduced by summarizing the analytical yield models and their steady state-stable age distribution assumption. In the model, annual yield at constant recruitment can be maximized by maximizing the yield from a single cohort throughout its life span. Excess exploitation levels that result in harvesting less than the maximum yield are what characterizes growth overfishing.

7. Two approaches to using the analytical yield model in order to regulate a fishery with the aim of optimizing yield or value are discussed. The first is to control the selectivity-at-age of the fishery (i.e. to regulate the sizes or ages of scallops that are harvested). The second approach is to control the overall effort of the fishery, either directly by effort limitation, or indirectly by catch limitations. The approaches are first discussed separately, and subsequently in combination. The yields per recruit associated with: a relaxed meat count (as observed during 1981 on the northern edge and northeast peak of Georges Bank), a 39 meat count, and a 26 meat count, are estimated. Following these strategies the fishery is selecting primarily ages 4, 5, and 6 (an age span relatively low on the growth curve). The predicted increase in yield per recruit, obtained by moving from a relaxed meat count (as observed in 1981) to a 26 meat count, is marginal. In order to benefit from the full growth potential of Placopecten a shift toward exploiting slightly older ages (5-, 6-, and 7-yr olds) is required. This would require a meat count in the order of 17. With such a shift, the increase in yield per recruit is over 50 percent, relative to present harvesting practices.

8. The second approach to preventing growth overfishing (i.e. the regulation of exploitation levels) is discussed in relation to the methodology of establishing catch limitations for scallops. The analysis for the northern edge and northeast peak of Georges Bank indicates that fishing mortalities have exceeded both $F_{0.1}$ and F_{max}

over the full period that can be analytically evaluated (1972 to 1983). Average F values for 4-, 5-, and 6-yr olds have varied between 0.5 and 1.1. F_{max} and $F_{0.1}$ levels for these ages and the 39 meat count selectivity pattern are 0.5 and 0.36 respectively. Thus, these Georges Bank scallop stocks have been growth overfished consistently since at least 1972. Under the current fishing strategy less than 17 percent of the possible egg production per recruit of the stock is produced. In sum, analysis of the second approach to preventing growth overfishing indicates that accumulated yield since 1972, at actual recruitment levels, would have been about 25 percent higher if $F_{0.1}$ exploitation levels had been maintained, and egg production would also have been significantly greater (about 35 percent of unfished potential rather than the less than 17 percent mentioned above).

9. The two approaches to optimizing yield (control of selectivity-at-age of the fishery and of the overall level of exploitation) are discussed in combination. With a shift in selectivity toward older ages (5-, 6-, and 7-yr olds), and a reduction in exploitation level to $F_{0.1}$, 58 percent more scallop landings could have been harvested from eastern Georges Bank during the 1972 to 1983 period from the actual recruitment that occurred. The yield loss may be considered a conservative estimate because of the possibility of higher levels of recruitment under the more biologically optimal strategy. At the optimal strategy, 35 percent of the egg production per recruit would be realized relative to the unfished state.

10. The present status of the several scallop stocks which are fished from Scotia-Fundy Region ports is summarized. The eastern Georges Bank stock is severely depleted, and the present management regime does not promote stock recovery. The regulatory vacuum caused by the disputed territorial status of eastern Georges Bank has contributed to this condition. It is not, however, concluded to be the sole reason because the other, considerably smaller, stocks in undisputed waters are also in a somewhat poor condition.

11. Management options from a biological point of view are briefly discussed. Effort control by such measures as catch limitations generated at $F_{0.1}$ exploitation levels will probably not promote stock rebuilding. The increase in yield per recruit will be marginal but the catch-rates would improve. It is concluded that a shift in the selectivity-at-age pattern toward 5-, 6-, and 7-yr olds (and thus a considerably lower meat count, ultimately to 17 meats per 500 g) is the option to take. The gains in yield, catch-rate, and egg production would all be very significant and the time frame of transition relatively short.

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Table 1. Catch statistics (tons of meats) for Georges Bank, NAFO Subdivision 5Ze. For Canada: Statistics from SA 5Z not separated into 5Ze and 5Zw prior to 1967. Source: Pre-1961 - Bourne (1964); 1961 on - ICNAF and NAFO Statistical Bulletins.

Year	U.S.A.	Canada	Total
1953	7,392	148	7,540
1954	7,029	103	7,132
1955	8,299	120	8,419
1956	7,937	318	8,255
1957	7,846	766	8,612
1958	6,531	1,179	7,710
1959	8,910	1,950	10,860
1960	10,039	3,402	13,441
1961	10,698	4,565	15,263
1962	9,725	5,715	15,440
1963	7,938	5,898	13,836
1964	6,322	5,922	12,244
1965	1,515	4,434	5,949
1966	905	4,878	5,783
1967	1,234	5,011	6,245
1968	998	4,820	5,818
1969	1,329	4,318	5,647
1970	1,420	4,097	5,517
1971	1,334	3,908	5,242
1972	824	4,161	4,985
1973	1,084	4,223	5,307
1974	929	6,137	7,066
1975	860	7,414	8,274
1976	1,777	9,675	11,452
1977	4,823	13,089	17,912
1978	5,589	12,189	17,778
1979	6,412	9,207	15,619
1980	5,477	5,221	10,698
1981	8,443	8,013	16,456
1982	6,523	4,307	10,830
1983	4,328	2,748	7,076

Table 2. Number of Canadian licensed offshore (>19.8 m LOA) vessels actively fishing on Georges Bank since 1958 according to the number of vessels submitting fish logs.

Year	No. of active vessels
1958	7
1959	14
1960	16
1961	23
1962	33
1963	44
1964	40
1965	48
1966	48
1967	43
1968	44
1969	43
1970	39
1971	41
1972	43
1973	65
1974	65
1975	66
1976	70
1977	73
1978	73
1979	75
1980	76
1981	75
1982	75
1983	74

Table 3. Landings for the Nova Scotia side of the Bay of Fundy. Data up to 1960 from Caddy (1979). Annual landings from 1960 to the present are those reported in Statistical Districts 37, 38, and 39. Source: Statistics Division, Management Services Branch, Department of Fisheries and Oceans, Scotia-Fundy Region, Halifax, N.S. B3J 2S7.

Year	Landings (t of meats)
1922-23	35.88
1923-24	26.26
1924-25	31.39
1925-26	59.65
1926-27	149.50
1927-28	243.03
1928-29	113.13
1929-30	90.31
1930-31	102.24
1931-32	55.66
1932-33	186.70
1933-34	231.79
1934-35	347.45
1935-36	483.76
1936-37	841.10
1937-38	579.10
1938-39	229.84
1939-40	140.07
1940-41	202.80
1941-42	309.40
1942-43	250.47
1943-44	223.85
1944-45	314.93
1945-46	382.06
1946-47	242.72
1947-48	203.75
1948-49	125.10
1949-50	36.02
1950-51	151.14
1951-52	76.84
1952-53	209.56
1953-54	343.87
1954-55	259.91
1955-56	249.79

.../Contd.

Table 3. Contd...

Year	Landings (t of meats)
1956-57	405.06
1957-58	551.24
1958-59	205.40
1959-60	186.13
1960	260.24
1961	386.02
1962	363.85
1963	530.24
1964	623.85
1965	496.15
1966	242.17
1967	166.02
1968	393.61
1969	277.12
1970	259.88
1971	196.38
1972	285.79
1973	164.82
1974	69.64
1975	125.55
1976	547.36
1977	934.70
1978	746.14
1979	787.35
1980	784.57
1981	1,262.29
1982	1,079.39

Table 4. Summary of Bay of Fundy and inshore licenses potentially landing scallops along southwest Nova Scotia. Source: Scotia-Fundy Licensing Unit, Fisheries Operations Branch, Department of Fisheries and Oceans, Scotia-Fundy Region, Halifax, N.S. B3J 2S7.

Year	Bay of Fundy	Inshore	Total
1979	73	24	97
1980	80	31	111
1981	96	35	131
1982	94	19	113

Table 5. Number of vessels based in New Brunswick and carrying a Bay of Fundy scallop license from 1978 to 1982. A Bay of Fundy license entitles the holder to drag for scallops in the Bay of Fundy and other areas of NAFO Division 4X and, under special permit, in Subdivision 5Ze. Source: Scotia-Fundy Licensing Unit, Fisheries Operations Branch, Department of Fisheries and Oceans, Scotia-Fundy Region, Halifax, N.S. B3J 2S7.

Year	⩽25.5 GT		>25.5 GT		Total
	⩽14 m	14-19.8 m	⩽14 m	14-19.8 m	
1978	14	0	0	6	20
1979	13	0	0	7	20
1980	13	0	0	7	20
1981	14	0	0	6	20
1982	8	0	4	4	16

Table 6. Number of vessels carrying an "inshore," or 7-mi, New Brunswick license for the period 1978 to 1982. This license entitles the holder to fish within 7 naut mi of the New Brunswick coast in the Bay of Fundy and the area defined as Lobster District 2 off Grand Manan Island. Source: Scotia-Fundy Licensing Unit, Fisheries Operations Branch, Department of Fisheries and Oceans, Scotia-Fundy Region, Halifax, N.S. B3J 2S7.

Year	≤25.5 GT		>25.5 GT		Total
	≤14 m	14-19.8 m	≤14 m	14-19.8 m	
1978	162	7	0	13	182
1979	1	0	0	1	est. 140
1980	114	5	0	16	135
1981	239	13	0	38	290
1982	213	9	14	42	278

Table 7. Annual landings (tons of meats) by statistical district - 1960 to 1983. Source: Statistics Division, Management Services Branch, Department of Fisheries and Oceans, Scotia-Fundy Region, Halifax, N.S. B3J 2S7.

Year	Statistical District						Total
	48	49	50	51	52	53	
1960			2.8				2.8
1961			1.9				1.9
1962			4.2	5.5		3.8	13.5
1963			4.8	5.5		3.3	13.6
1964			0.8	4.7		2.4	7.9
1965	0.2		7.8	1.8		2.8	12.6
1966			0.9	0.9			1.8
1967				0.5	1.8	2.8	5.1
1968			14.5	3.6	0.5	1.8	20.4
1969						0.9	0.9
1970			7.7		1.3	1.3	10.3
1971			1.8	0.9	1.8	4.9	9.4
1972			1.8	0.5		3.6	5.9
1973			4.6	1.8		2.8	9.2
1974			1.3	1.3		2.4	5.0
1975			0.7	2.1		1.1	3.9
1976			0.2	1.3			1.5
1977			3.5	0.2	0.5		4.2
1978			10.2		1.7		11.8
1979			24.7	2.0	3.4		30.1
1980			145.2	9.0	9.5	0.2	163.9
1981	0.1	2.2	487.6	50.6	12.9	8.1	561.5
1982	3.4	3.5	240.6	22.0	22.6	1.8	293.9
1983	5.0	14.9	265.1	46.1	3.4	6.3	340.8

Table 8a. Summary of Nova Scotia scallop fishery regulations.

Effective date	Nature of regulation
April 13, 1918	- license required - closed season June 1 to September 15 - minimum size 4 inches
June 5, 1920	- no exporting of scallops to outside Nova Scotia
December 18, 1920	- closed season extended June 1 to October 15 - waste portions not to be thrown overboard on scallop grounds - soaking in freshwater prohibited - fishing season in Mahone Bay restricted to December 15 to January 20
April 29, 1922	- special season changed to November 15 to December 30 for Lunenburg County and December 1 to January 31 for Digby Basin - regulations not applicable beyond territorial waters
November 11, 1922	- special seasons changed to November 1 to April 30 for Lunenburg County
March 13, 1926	- minimum ring size in rakes of 4 inches
May 29, 1926	- regulations applicable outside territorial waters
October 29, 1927	- season starts September 15 for this year only
March 22, 1930	- season in Digby Basin closed until February 1935 and thereafter restricted to February
May 4, 1935	- closed season for outside territorial waters changed to June 11 to September 30
April 25, 1936	- closed season changed to June 1 to September 30 for inside and outside territorial waters - minimum ring size 3 inches
September 25, 1937	- closed season changed to May 1 to October 14

.../Contd.

Table 8a. Contd...

Effective date	Nature of regulation
October 29, 1938	- total combined gear width restricted to 18 ft
May 6, 1939	- for 1939 only, season extended to May 10
January 27, 1940	- gear width restriction not applicable to offshore Atlantic banks
May 4, 1940	- for 1940 only, season extended to May 10
April 26, 1941	- for 1941 only, season extended to May 17
September 13, 1941	- closed season changed to May 1 to September 30
May 27, 1944	- restriction on throwing waste portions on scallop grounds rescinded
February 3, 1945	- season and gear width restrictions not applicable to outside territorial waters, south and east of a line due west of Cape Sable
May 28, 1947	- closed season restricted to Bay of Fundy proper but gear width restrictions apply
May 12, 1948	- closed season restricted to outer half of Bay of Fundy - gear width restriction limited to outer Bay of Fundy, Digby Basin, and Lunenburg County
July 13, 1949	- part of Lunenburg Harbour closed until November 1, 1951
February 14, 1951	- closed season restricted to inshore Digby area
May 13, 1953	- minimum scallop size dropped - minimum ring size increased to 3-1/4 inches but restricted to Bay of Fundy
December 31, 1954	- special season for Digby Basin dropped
September 13, 1961	- closed season changed to May 1 to August 31 for inshore Digby area

.../Contd.

Table 8a. Contd...

Effective date	Nature of regulation
May 22, 1963	- minimum ring size dropped
March 11, 1970	- SCUBA diving for scallops permitted with license
March 28, 1973	- license fees increased
June 11, 1975	- special closed season for Digby Gut and Annapolis Basin May 1 to November 30
April 14, 1976	- minimum ring size reintroduced - 3-1/4 inches
June 28, 1978	- bag limit of 100 scallops for SCUBA diving
January 14, 1981	- scallop license fees taken out, except for SCUBA diving which were increased

Table 8b. Summary of New Brunswick scallop fishery regulations.

Effective date	Nature of regulation
April 13, 1918	- license required - closed season June 15 to September 15 - 4-inch minimum size
December 18, 1920	- closed season changed to June 1 to October 15 - waste portions not to be thrown overboard on scallop grounds - soaking in freshwater prohibited
April 29, 1922	- regulations not applicable beyond territorial waters
October 11, 1924	- for 1924 only, season can begin September 22
March 13, 1926	- ring size in scallop rakes not less than 4 inches
May 29, 1926	- regulations apply inside and outside territorial waters
October 29, 1927	- for 1927 only, season starts September 15
March 24, 1934	- no scallop fishing on Sunday in Charlotte County
May 20, 1939	- total combined length of drags not to exceed 18 ft
June 3, 1939	- around Grand Manan, combined length of drags not to exceed 9 ft
May 4, 1946	- special gear restriction for Grand Manan rescinded
April 28, 1948	- closed season changed to May 1 to September 30 - minimum ring size changed to 3 inches
July 14, 1948	- closed season and gear width restrictions limited to outer section of Bay of Fundy
January 9, 1952	- closed area on east side of Grand Manan Island between Long and Whitehead Islands
October 1, 1952	- closed area regulation rescinded

.../Contd.

Table 8b. Contd...

Effective date	Nature of regulation
December 22, 1954	- minimum ring size in Bay of Fundy proper increased to 3-1/4 inches - minimum size restriction dropped
May 11, 1955	- closed season restricted to inshore Digby area - gear width restriction dropped
September 27, 1978	- SCUBA diving bag limit of 100 scallops
January 14, 1981	- scallop license fees taken out, except for SCUBA diving which were increased

Table 8c. Summary of offshore scallop regulations.

Effective date	Nature of regulation	Regulations*
April 25, 1973	For vessels over 65 ft in Areas 5Ze, 5Zw, 4W, or 4X: - minimum shell size 81.5 mm (2-1/4 inch) - meat count of 60 meats/lb with 5% margin for error	NWAFCR SOR/73-211
June 27, 1973	- logbooks required for vessels in excess of 25 GT	NWAFCR SOR/73-317
April 10, 1974	- meat count of 50 meats/lb for vessels over 65 ft	NWAFCR SOR/74-187
October 9, 1974	- scallop regulations apply to vessels over 65 ft in all convention areas	NWAFCR SOR/74-547
December 24, 1975	- meat count of 45 meats/lb	NWAFCR SOR/75-679
April 14, 1976	- scallop fishery of limited entry	AFRLR SOR/76-211
September 22, 1976	- shell size increased to 95 mm (3-3/4 inches) - meat count of 40 meats/lb - margin for error on meat count increased to 10%	NWAFCR SOR/76-584
June 8, 1977	- formation of Atlantic Fishery Regulations (contains all current scallop regulations found in NWAFCR)	AFR SOR/77-411
October 12, 1977	- trip quota of 13,608 kg - 4-mo quota of 81,648 kg for July 16 to November 15, 1977, and November 16, 1977, to March 15, 1978 - Maximum 12-da trip including days of departure and landing	AFR SOR/77-768
July 12, 1978	- 4-mo quotas of 81,648 kg for April 1 to July 31, 1978, August 1 to November 30, 1978, December 1, 1978, to March 31, 1979	AFR SOR/78-553

.../Contd.

Table 8c. Contd...

Effective date	Nature of regulation	Regulations*
May 23, 1979	- 4-mo quotas apply to April 1 to July 31 in any year, August 1 to November 30 in any year, December 1 in any year to March 31 the following year - logbook required for vessel in excess of 25.5 GT or more than 14 m LOA	AFR SOR/79-405
December 26, 1979	- Northwest Atlantic Fisheries Regulations revoked	NWAFR SOR/79-945
January 14, 1981	- scallop license fees increased; $200 for vessels 65 to 90 ft, $1,500 for vesSels over 90 ft	AFRLR SOR/81-14
September 9, 1981	- minimum shell size rescinded	AFR SOR/81-658
February 10, 1982	- special trip permit required for a vessel less than 19.8 m to fish scallops in 5Ze - scallops added to Schedule III (closed times and quotas) of Atlantic Fishery Regulations - closed season December 20 to December 31 in 5Ze and 4X; quotas of 165 t for Class D and E vessels in 5Ze; 10,000 t for Class F, G, H, I, J, K, L, and M vessels in 5Ze; 1,600 t for D and E class vessels in 4X; 1,100 t for F, G, H, I, J, K, L, and M class vessels in 4X outside territorial waters; and a quota of 0 and closed season of January 1 to December 31 for the same vessels inside territorial waters of 4X	AFT SOR/82/195
October 13, 1982	- Trinity Ledge closed	AFR SOR/82-899
November 10, 1982	- regulations apply to Chlamys islandica as well as Placopecten magellanicus	AFR SOR/82-977

.../Contd.

Table 8c. Contd...

Effective date	Nature of regulation	Regulations*
July 27, 1983	- meat count reduced to 39 meats/ 500 g (35 meats/lb) - quotas removed from Schedule III	AFR SOR/83-582
January 11, 1984	- creation of recreational scallop fishing license, fee $5; other fees increased; for vessel greater than 27.4 m - $2,000; for vessel 19.8 to 27.4 m - $200; others - $30	AFRLR SOR/84-60

*NWAFCR - Northwest Atlantic Fisheries Convention Regulations
AFRLR - Atlantic Fishing Registration and Licensing Regulations
AFR - Atlantic Fishery Regulations

Table 9. Characteristics of beds of Chlamys opercularis.

Bed	Landings (round weight)	Spawning	Permanence of beds
1	220 t/yr	no info.	Presence - 17 yr Fishery - 11 yr
2,3	1,116 t/yr	May-June, autumn, winter	Presence - 120 yr Fishery - 16 yr
4	no info.	no info.	Fished 1972-1973
5	8.6 t/yr	no info.	Fishery - 15 yr
6	5,000 t/yr	Jan.-Feb., June-July, Sept.-Oct.	Presence - 75+ yr Fishery - 16 yr
7	1,678 t/yr	winter, June-July, autumn	Presence - 135+ yr Fishery - 135+ yr
8	233 t/yr	no info.	Presence - 100+ yr Fishery - 15 yr
9	647 t/yr	summer spawning later than June-July	Presence - 100+ yr Fishery - 14 yr
10	1,023 t/yr	no info.	Fishery Oct. 1971 to late 1973; recovery to initial abundance since then

Table 10. Characteristics of beds of Pecten maximus.

Bed	Landings (round weight)	Spawning	Permanence of beds
1	175 t/yr	France in general June to August	Fishery - 55 yr
2	100 t/yr	France in general June to August	Fishery - 55 yr
3	200 t/yr	France in general June to August	Fishery - 55 yr
4	300 t/yr	France in general June to August	Fishery - 60 yr
5	30 t/yr	France in general June to August	Fishery - 55 yr
6	80 t/yr	France in general June to August	Fishery - 55 yr
7	50 t/yr	France in general June to August	Fishery - 55 yr
8	220 t/yr	June to August	Fishery - 130+ yr
9	7,728 t/yr	June to August	Fishery - 200+ yr
10	4,300 t/yr	no info.	Fishery - 55+ yr
11	3,500 t/yr	no info.	Fishery - 55+ yr
12	844 t/yr	May to Oct., peak July-August	Fishery - 80+ yr
13	2,528 t/yr includes 14	no info.	Presence - 100+ yr Fishery - 55+ yr
14	included in 13	no info.	Fishery - 55+ yr
15	4 t/yr	no info.	Presence - 10+ yr
16	no info.	some year around, peaks spring and autumn	no info., at least 5 yr

.../Contd.

Table 10. Contd...

Bed	Landings (round weight)	Spawning	Permanence of beds
17	2,150 t/yr	April-May and Aug-Sept., occasional July-early August	Fishery - 75+ yr
18	154 t/yr	spring, Aug. Sept.; spring peak varies from March-April to June-July	Presence - 120+ yr Fishery - 40+ yr
19	1,022 t/yr	no info.	Fishery - 20+ yr
20	sporadic and variable	spring peaks May-June	Fishery - 15+ yr
21	no info.	no info.	Fishery - 7 yr
22	210 t/yr	no info.	Fishery - 15 yr
23	251 t/yr	no info.	Fishery - 17 yr
24	no info.	no info.	Fished in 1971
25	133 t/yr	May-June, Aug.-Sept.	Presence - 120+ yr Fishery - 45+ yr
26	30 t/yr	spring-summer, autumn	Fishery - 120+ yr
27	no info.	May-June, July	Fishery - 9+ yr
28	44 t/yr	no info.	Fishery - 45+ yr

Table 11. Characteristics of beds of Placopecten magellanicus.

Bed	Landings (round weight)	Spawning	Permanence of beds
1,2	393 t/yr	Sept.-Oct.	Presence - 50+ yr
3,4	648 t/yr	no info.	Presence - 30+ yr
5	983 t/yr	Sept.	Fishery - 25+ yr
6,7,8	1,660 t/yr	July-Sept.	Presence - 55+ yr Sporadic fishing - 30+ yr
9	212 t/yr	Aug.-Sept.	Sporadic fishing - 40 yr
10	108 t/yr	Sept.-Oct.	Sporadic fishing - 20+ yr
11	161 t/yr	Sept.-Oct.	Fishery - 10 yr Presence - 20 yr
12	2,698 t/yr	Aug.-Sept.	Fishery - 60 yr Presence - 350+ yr
13	948 t/yr	Aug.-Sept.	Presence - 60+ yr
14	1,517 t/yr	Aug.-Oct.	Presence - 100+ yr
15,16, 17	68,980 t/yr	Sept.-Oct.	Fishery - 50+ yr
18	463 t/yr	Sept.-Oct.	Fishery - 20+ yr
19A	24,898 t/yr	August	Fishery - 60+ yr
19B	17,971 t/yr	July-August	Fishery - 60+ yr
19C	1,839	July	Fishery - 60+ yr

Table 12. Georges Bank selectivity-at-age vectors and associated analytical yield model results given the stock distribution-at-age present and the meat count rule to be met.

Age	1983 fishery (39 meat count)	1981 fishery (relaxed meat count)	Option A (26 meat count)	Option B (17 meat count)
3	0.02	0.04	0.01	0
4	0.77	0.91	0.46	0
5	1.00	1.00	1.00	0.30
6	0.58	0.51	0.58	0.60
7	0.37	0.28	0.37	1.00
8	0.26	0.21	0.26	0.60
9	0.14	0.17	0.14	0.40
10	0.12	0.14	0.12	0.20
11	0.11	0.07	0.11	0.11
12	0.15	0.04	0.15	0.15
13+	0.28	0.29	0.28	0.28

	Y (g) per meat unit	F ($\bar{F}$)	Y/E (at max)	Y (g) per meat unit	F	Y/E (at 0.1)
1983 selectivity	12.5	0.72 (0.34)	17.4	11.9	0.46	25.7
1981 selectivity	11.8	0.73 (0.36)	16.2	11.3	0.47	23.9
Option A	13.4	0.83 (0.32)	16.2	12.7	0.52	23.1
Option B	18.2	1.09 (0.26)	16.7	17.0	0.59	28.9

Table 13. The relative amounts of pre-spawning ovary biomass in a stable age distribution at various fishing levels.

F	1983 fishery (39 meat count) PR_{83} Ovary Biomass (%)	Option B (17 meat count) PR_{17} Ovary Biomass (%)
0	100	100
0.1	79	83
0.2	64	69
0.3	51	59
0.4	42	51
0.5	35	45
0.6	30	41
0.7	25	37
0.8	22	34
0.9	19	31
1.0	17	29

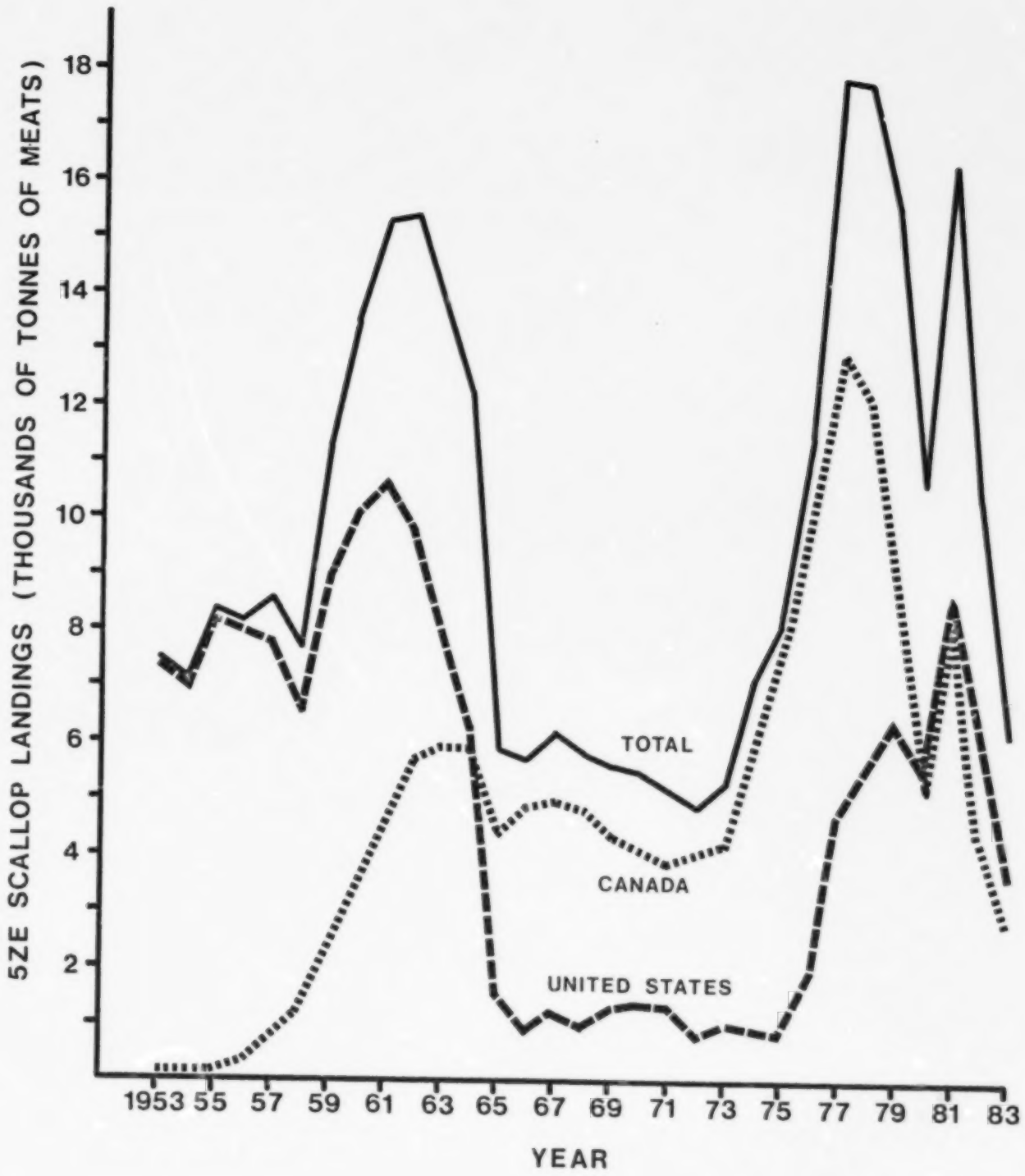
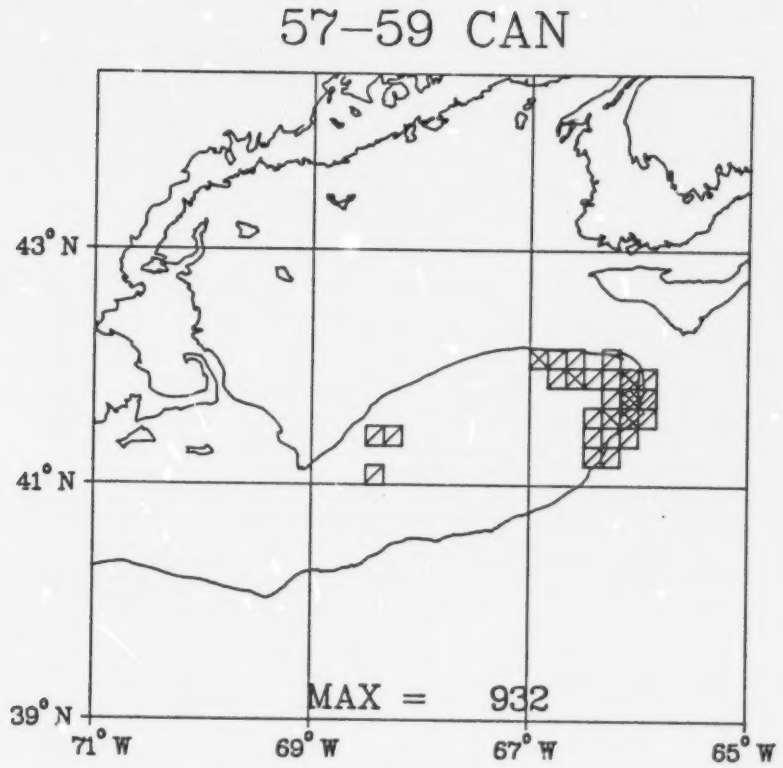


Fig. 1. Scallop landings from 5Ze by Canada and the United States, 1953 to 1983.

Fig. 2a to 2h. Distribution of scallop landings by 10 min^2 by Canada and the United States. The maximum landings by 10 min^2 for the respective 3-yr time periods are indicated by MAX (in tons of meats). The squares are coded as follows:

= 80% to 100% of MAX
= 60% to 80% of MAX
= 40% to 60% of MAX
= 20% to 40% of MAX
= 1% to 20% of MAX
= no catch reported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41° N
39° N
MAX = 932
71° W
69° W
67° W
65° W

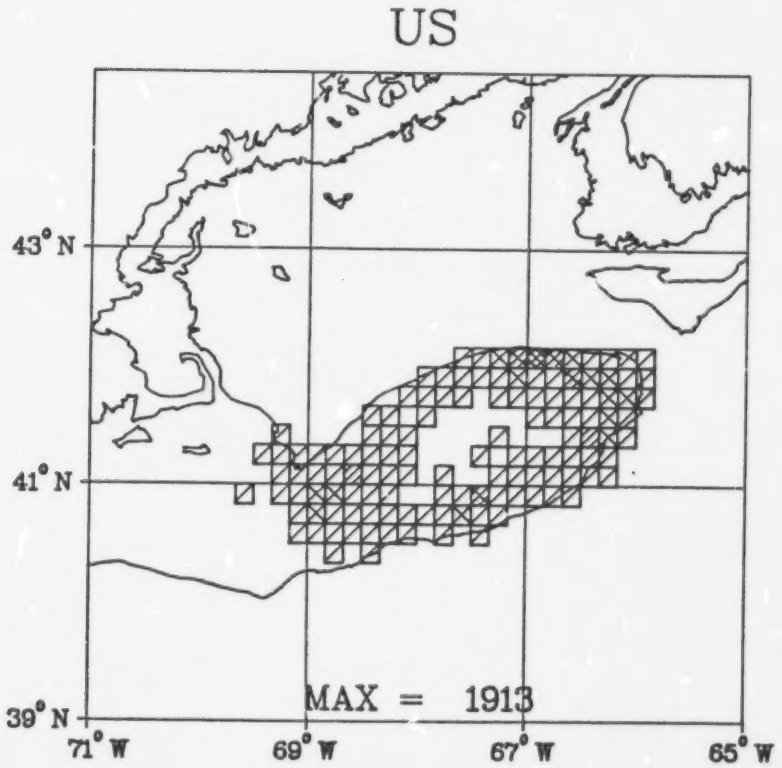
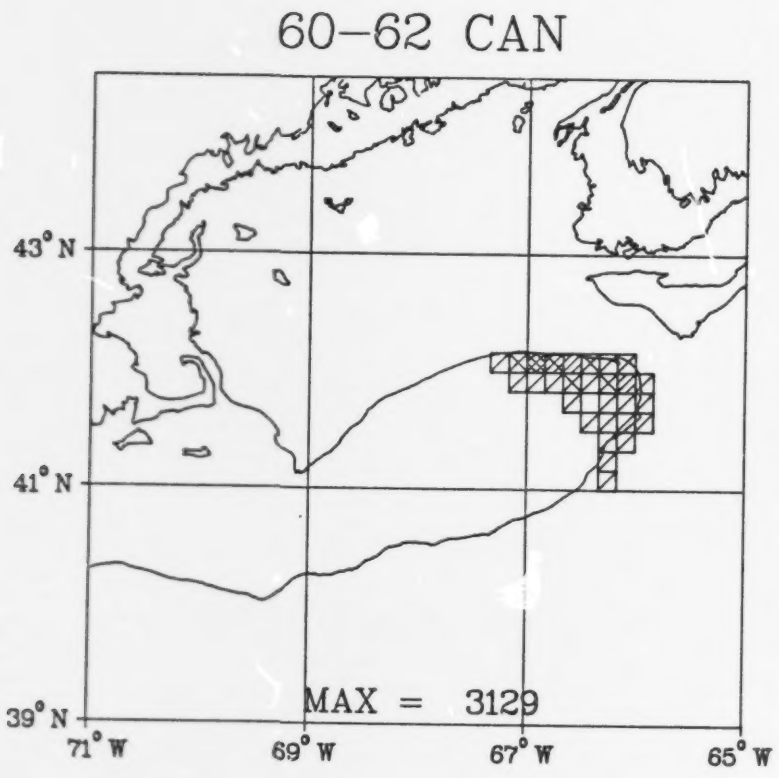

US
43° N
41° N
39° N
MAX = 1913
71° W
69° W
67° W
65° W

Fig. 2a.


60–62 CAN
43° N
41° N
39° N
71° W
69° W
67° W
65° W
MAX = 3129

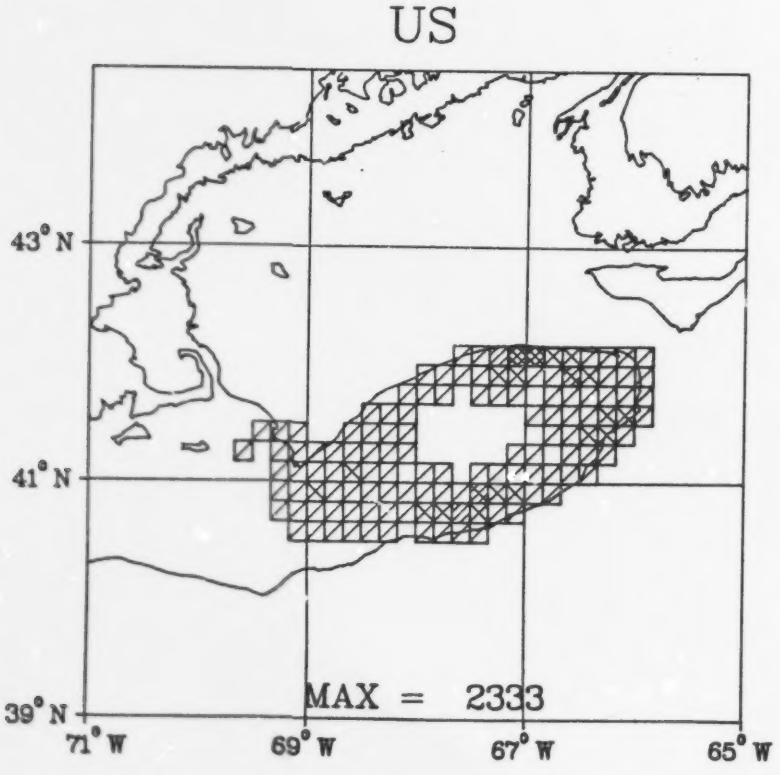
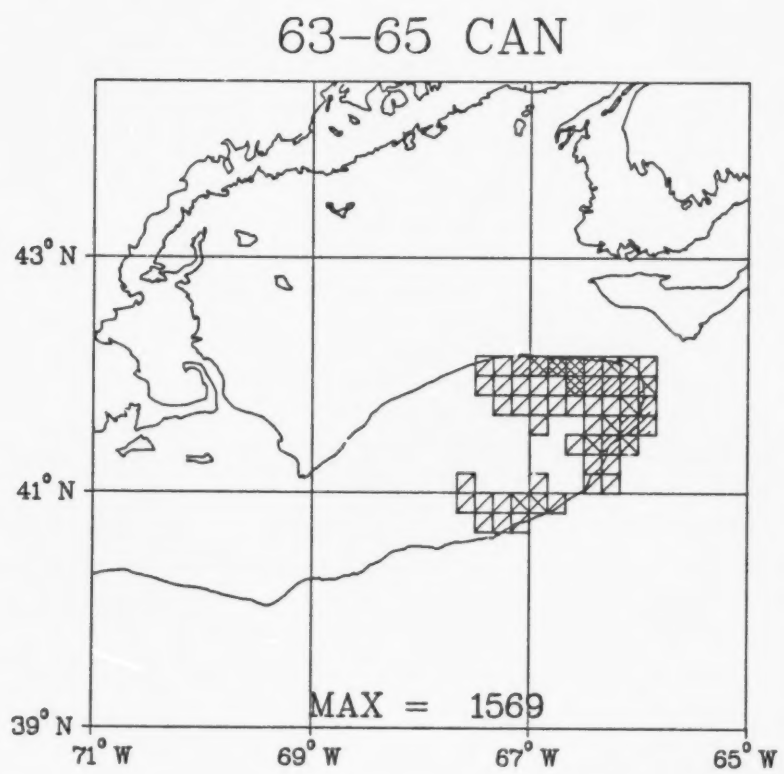

US
43° N
41° N
39° N
71° W
69° W
67° W
65° W
MAX = 2333

Fig. 2b.


63–65 CAN
43° N
41° N
39° N
MAX = 1569
71° W
69° W
67° W
65° W

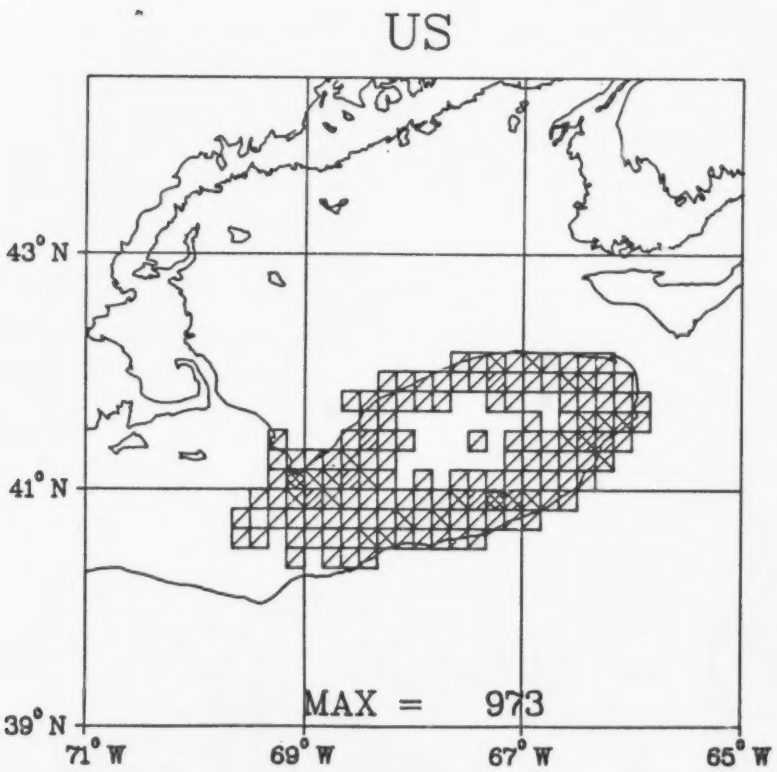
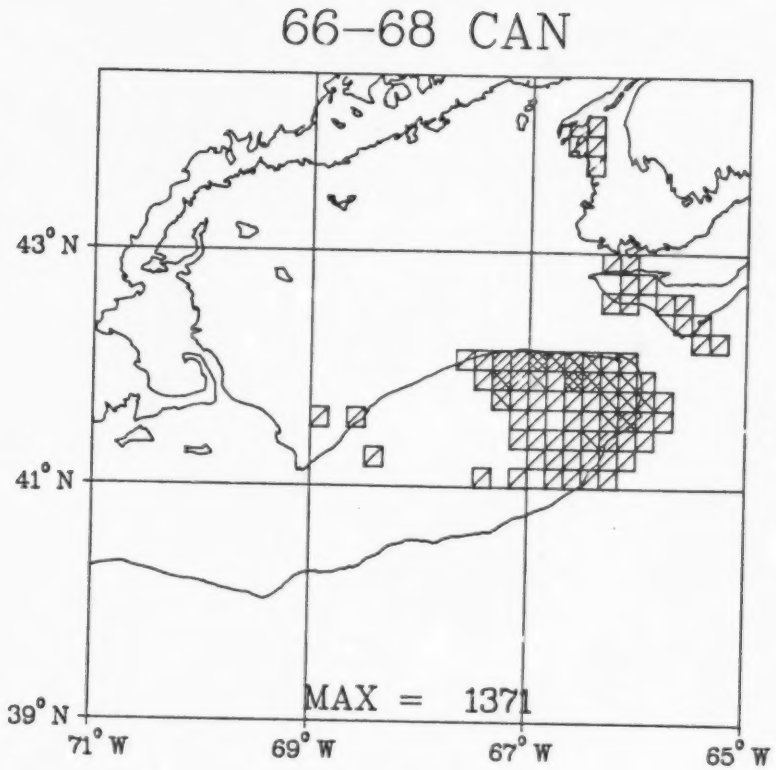

US
43° N
41° N
39° N
MAX = 973
71° W
69° W
67° W
65° W

Fig. 2c.


66–68 CAN
43° N
41° N
39° N
MAX = 1371
71° W
69° W
67° W
65° W

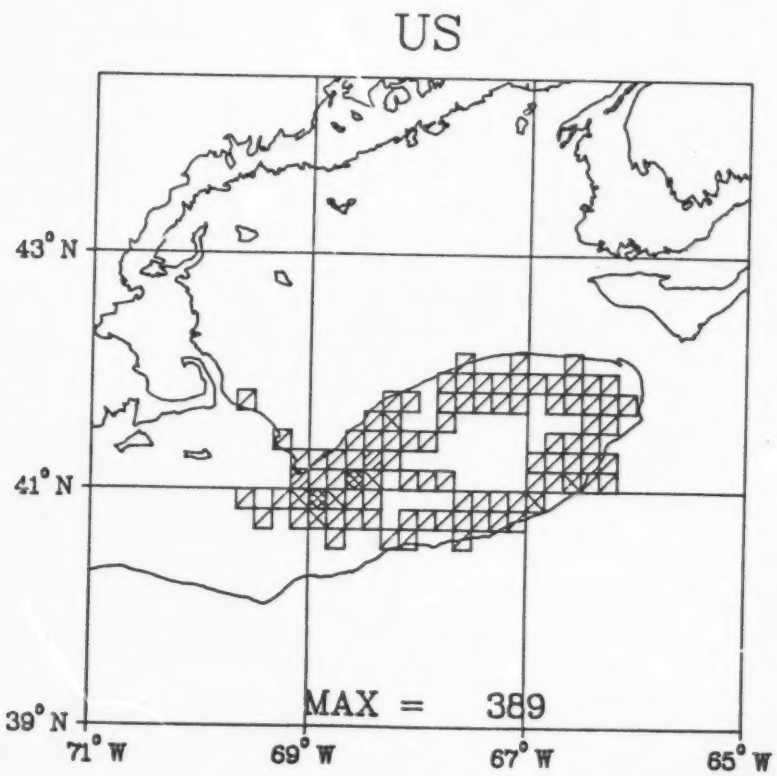
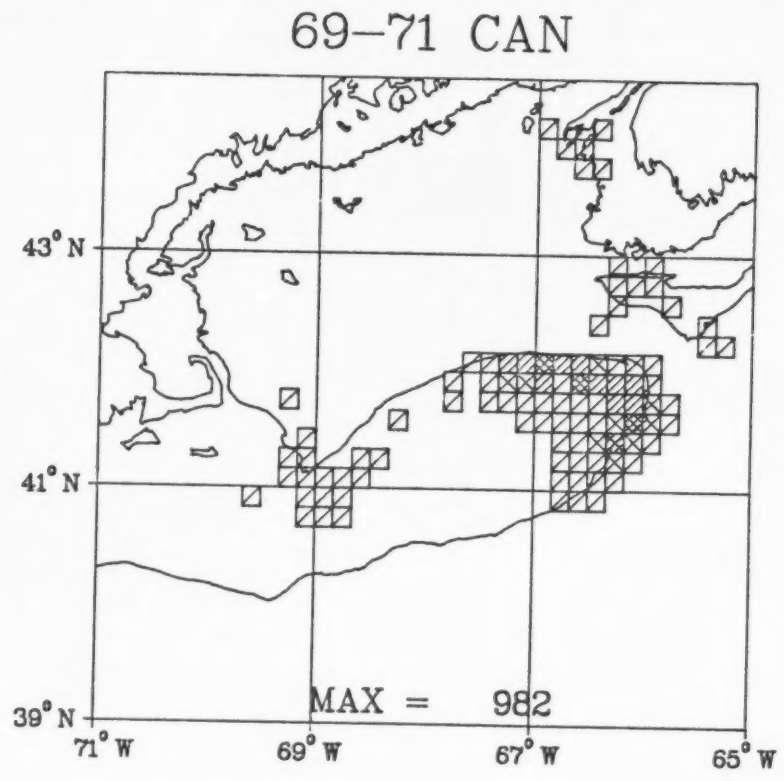

US
43° N
41° N
39° N
MAX = 389
71° W
69° W
67° W
65° W

Fig. 2d.


69–71 CAN
43° N
41° N
39° N
MAX = 982
71° W
69° W
67° W
65° W

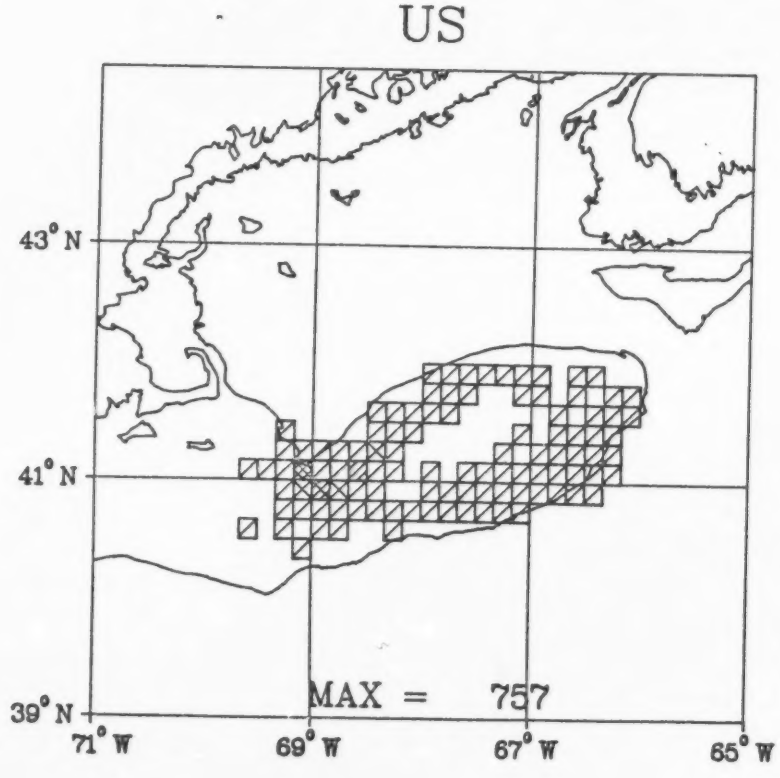
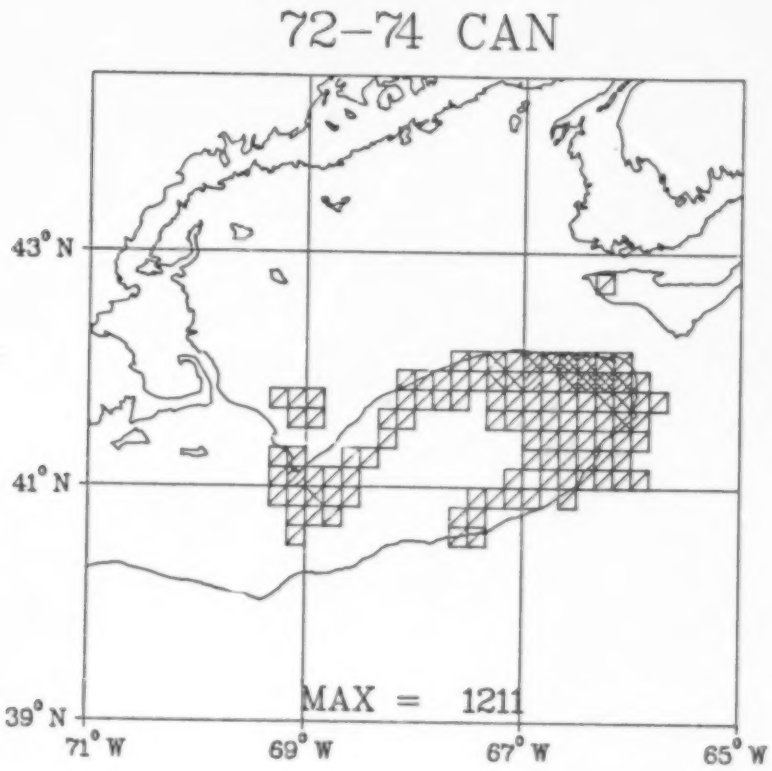

US
43° N
41° N
39° N
MAX = 757
71° W
69° W
67° W
65° W

Fig. 2e.


72–74 CAN
43° N
41° N
39° N
MAX = 1211
71° W
69° W
67° W
65° W

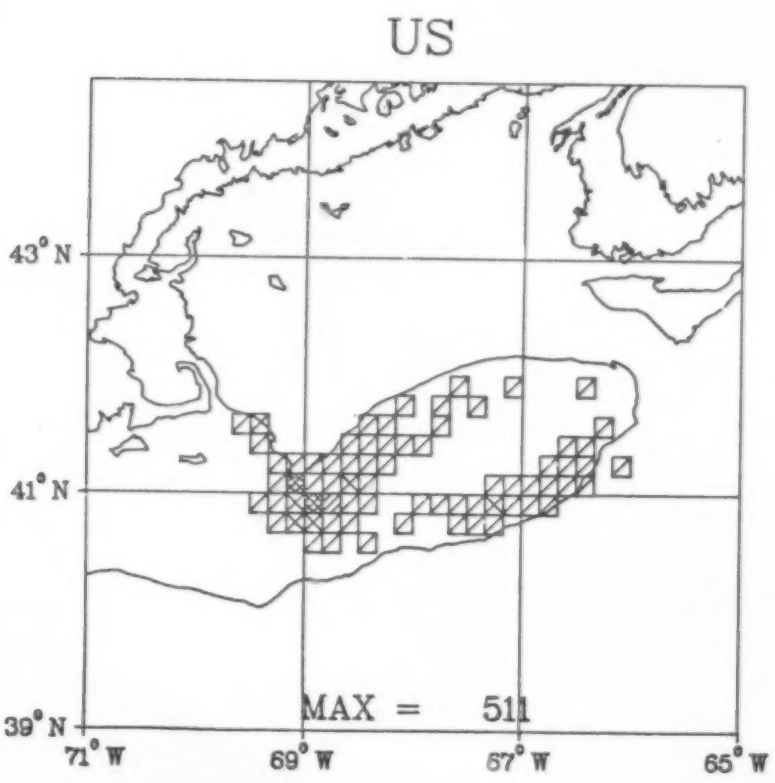
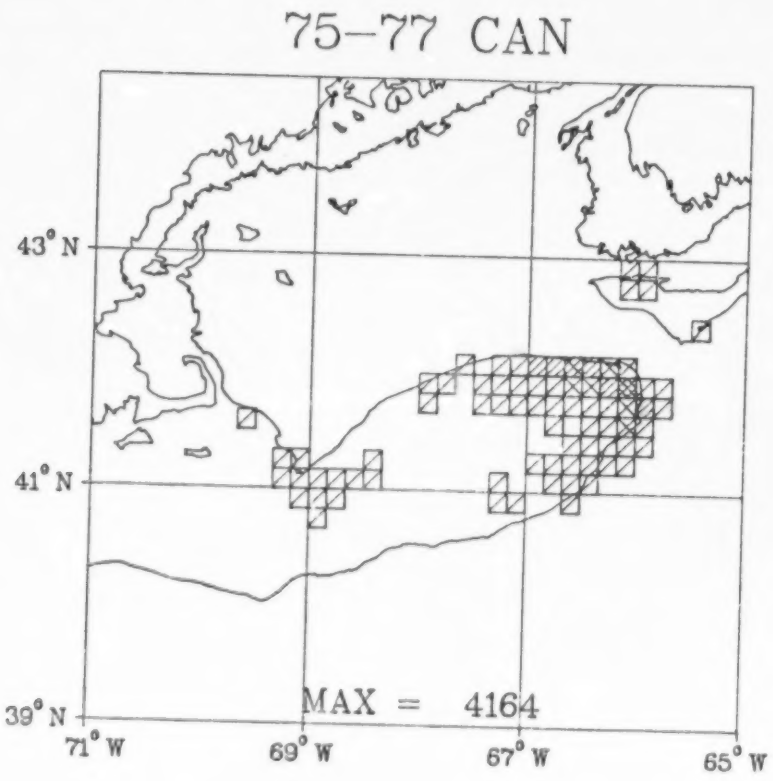

US
43° N
41° N
39° N
MAX = 511
71° W
69° W
67° W
65° W

Fig. 2f.


75–77 CAN
43° N
41° N
39° N
MAX = 4164
71° W
69° W
67° W
65° W

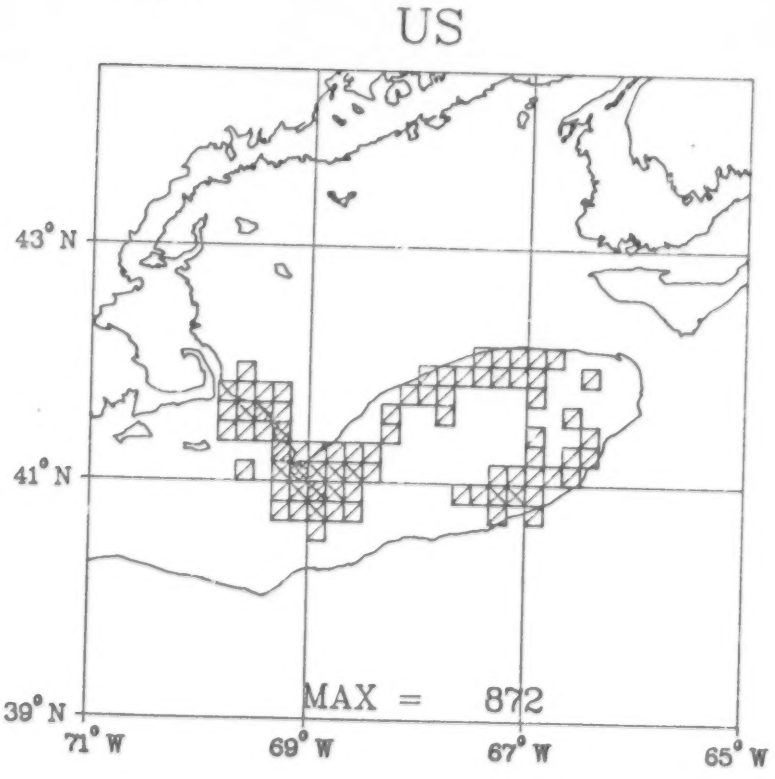
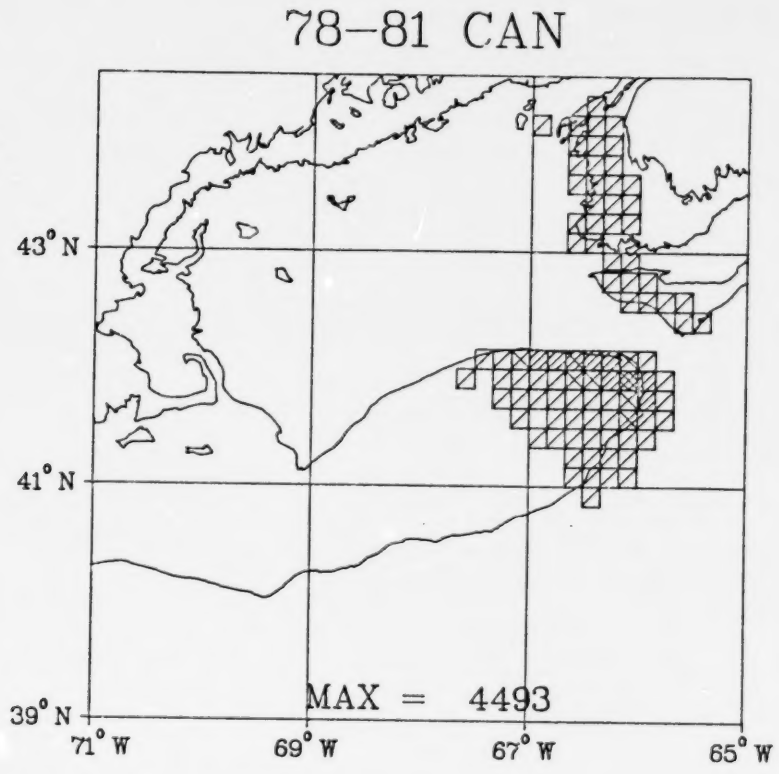

US
43° N
41° N
39° N
MAX = 872
71° W
69° W
67° W
65° W

Fig. 2g.


78–81 CAN
43° N
41° N
39° N
MAX = 4493
71° W
69° W
67° W
65° W

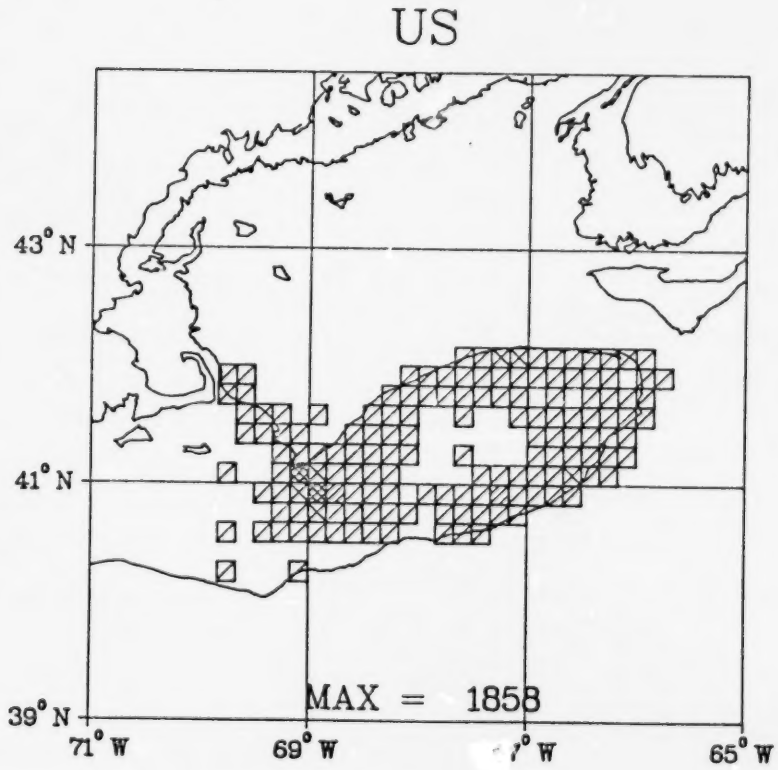

US
43° N
41° N
39° N
MAX = 1858
71° W
69° W
65° W

Fig. 2h.

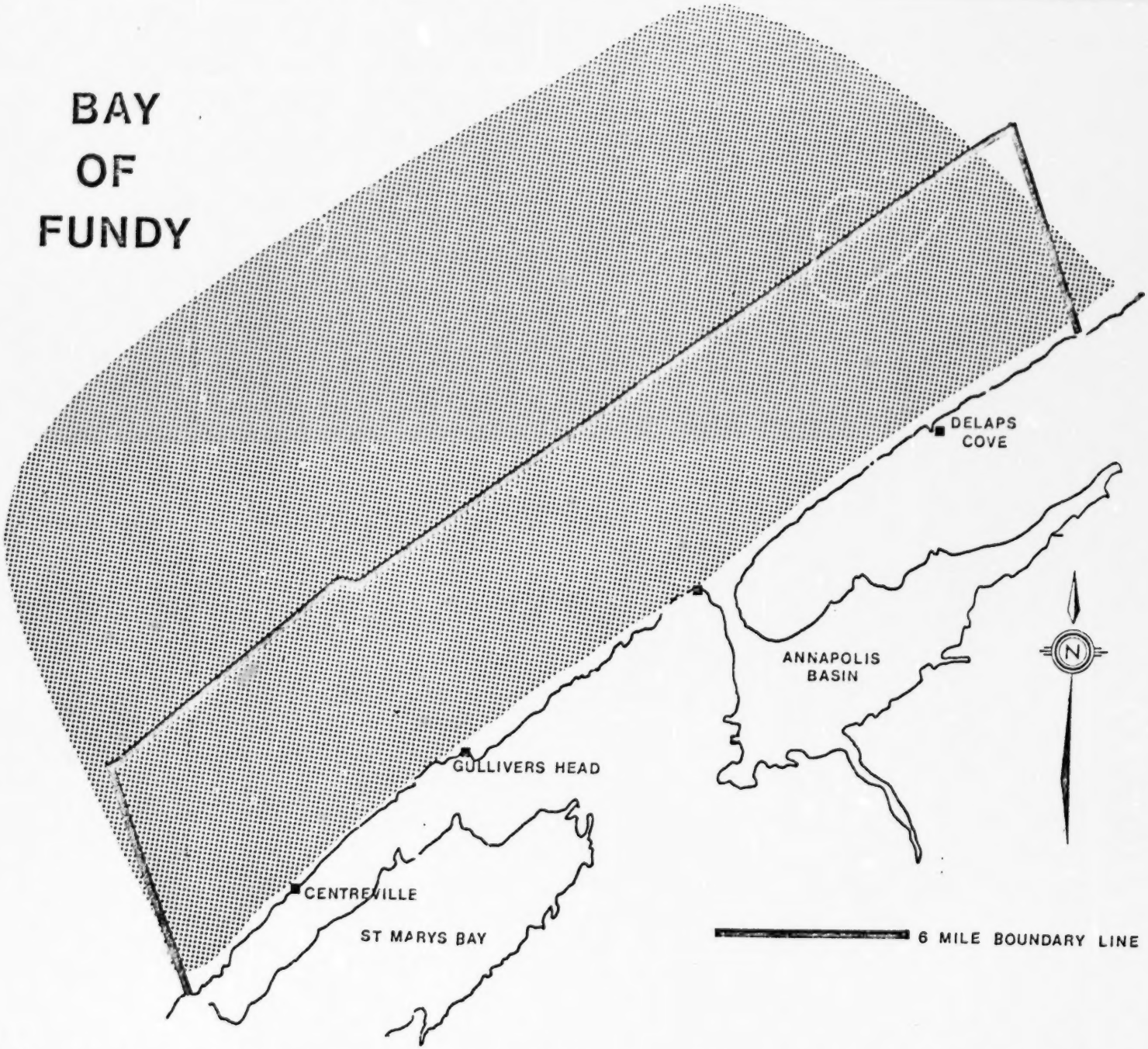


Fig. 3. Distributional area of the traditional scallop fishery on the Nova Scotia side of the Bay of Fundy. The inside 6-mi summer closure area is enclosed by the heavy solid line.

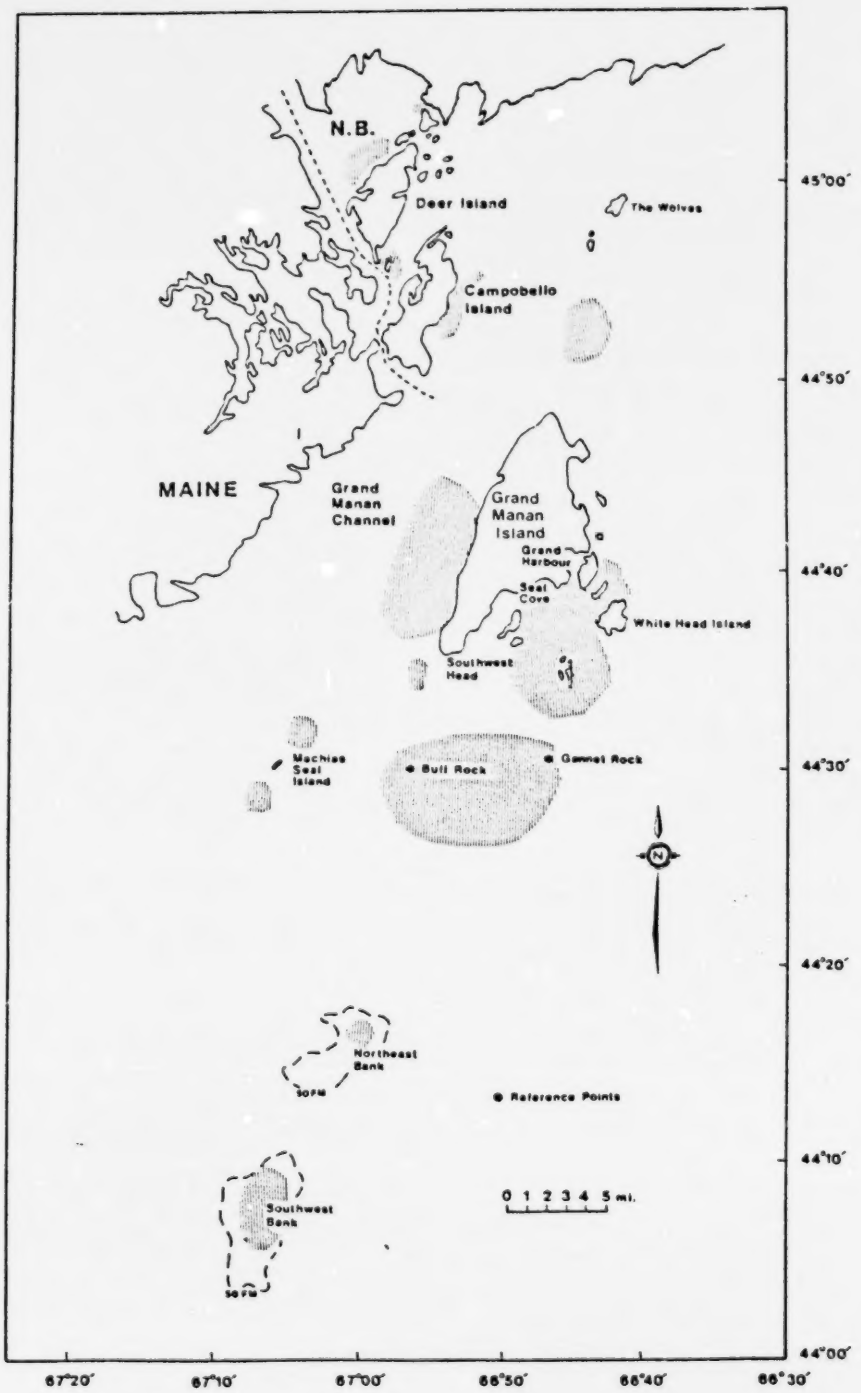


Fig. 4. Estimated location of scallop fishing grounds exploited by New Brunswick-based vessels, mainly on Grand Manan Island.

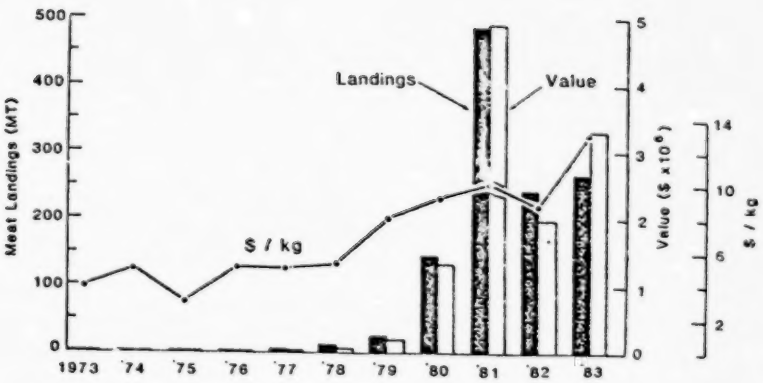


Fig. 5. Grand Manan Island (District 50) scallop landings and value, 1973-1983. Line traces the annual average scallop meat price per kilogram.

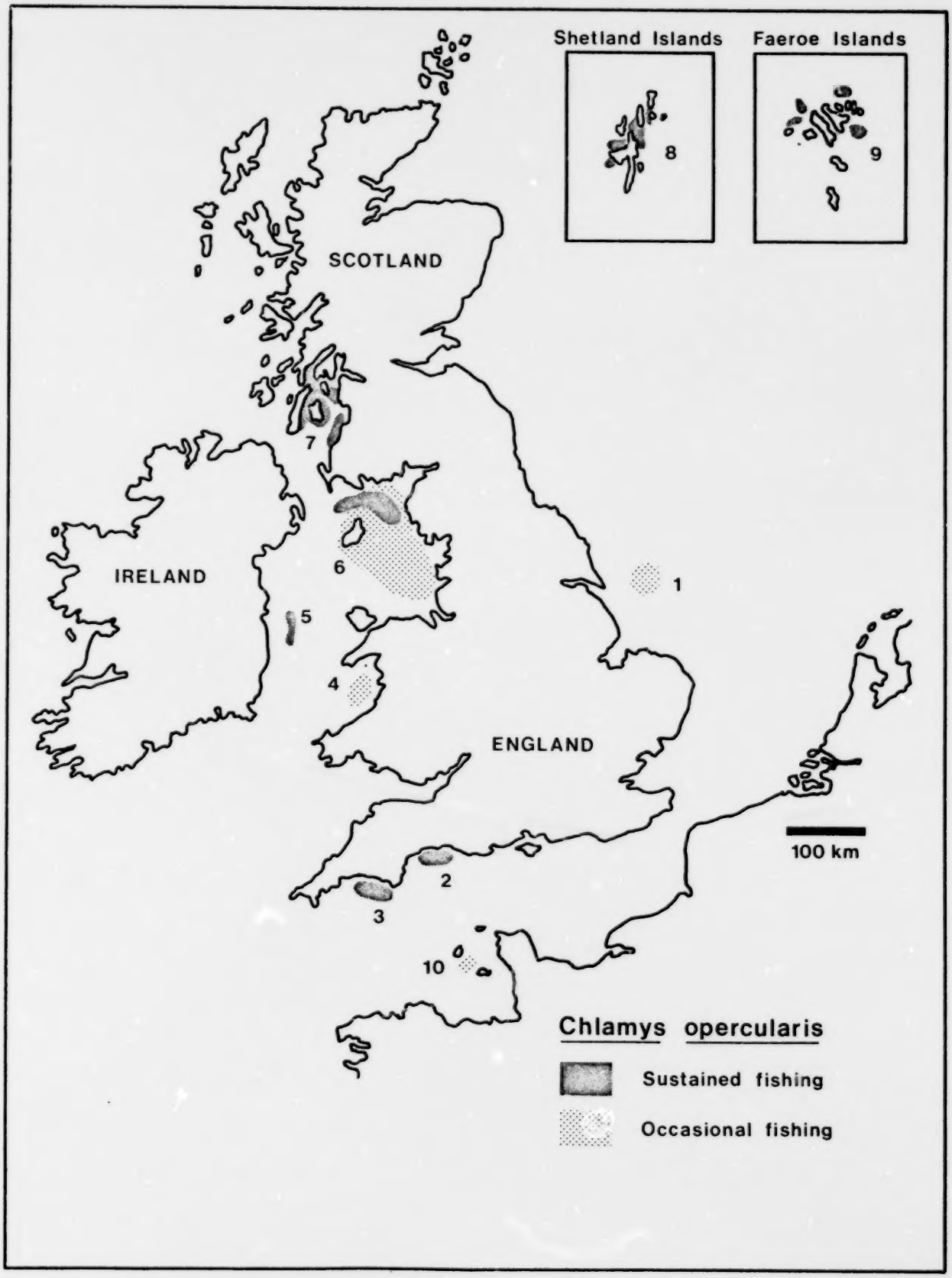


Fig. 6. Distribution of Chlamys opercularis fishing areas.

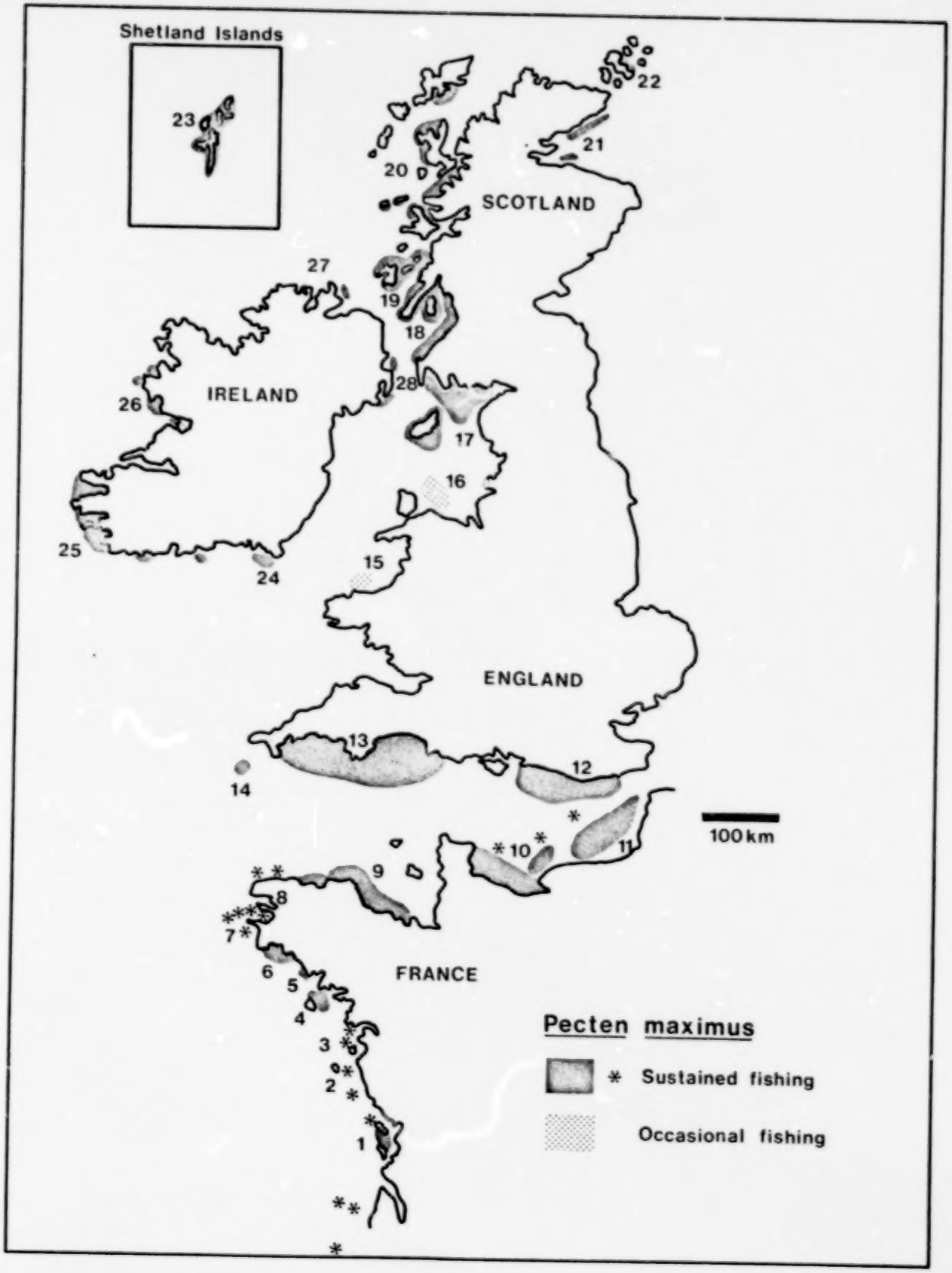


Fig. 7. Distribution of Pecten maximus fishing areas.

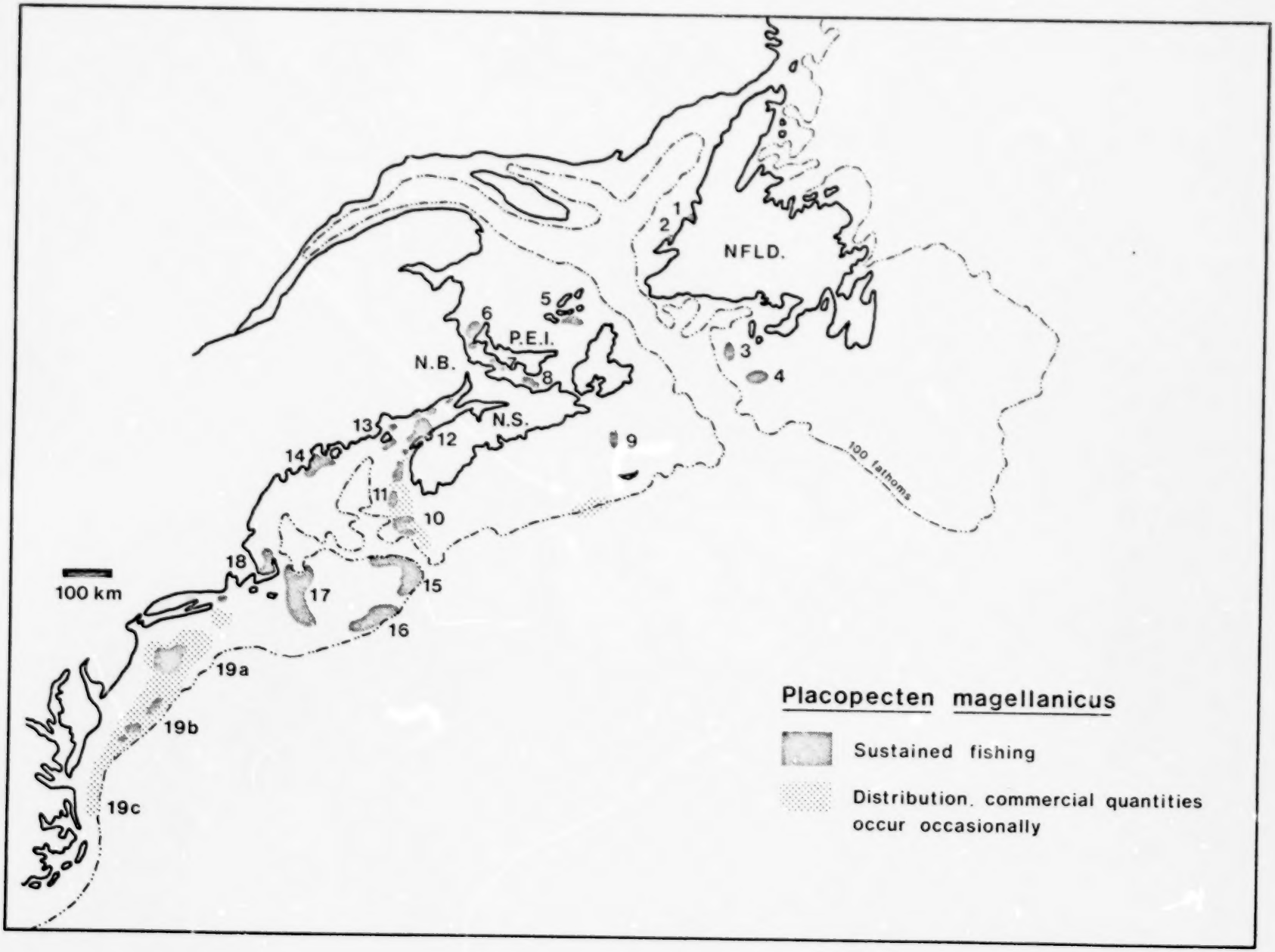


Fig. 8. Distribution of Placopecten magellanicus fishing areas.

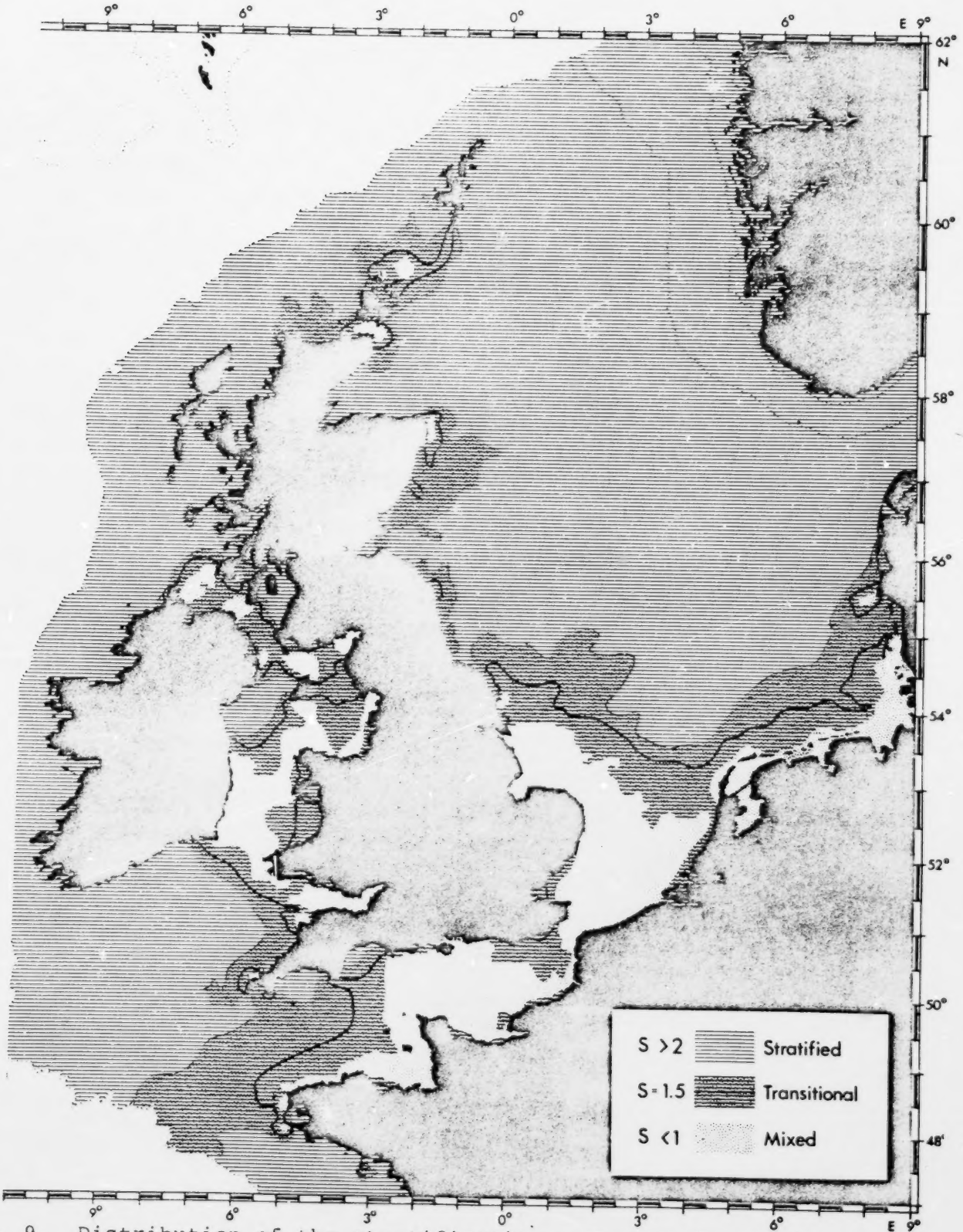


Fig. 9. Distribution of the stratification parameter in northeast Atlantic shelf seas. Bold line identifies frontal regions (s=1.5) between stratified and well-mixed water columns.

Fig. 10. Distribution of the stratification parameter in the Gulf of Maine area. Frontal regions at interface between shaded and unshaded areas at $H/u^3 = 1.9$ divide stratified and well-mixed areas. [From Garrett et al. (1978).]

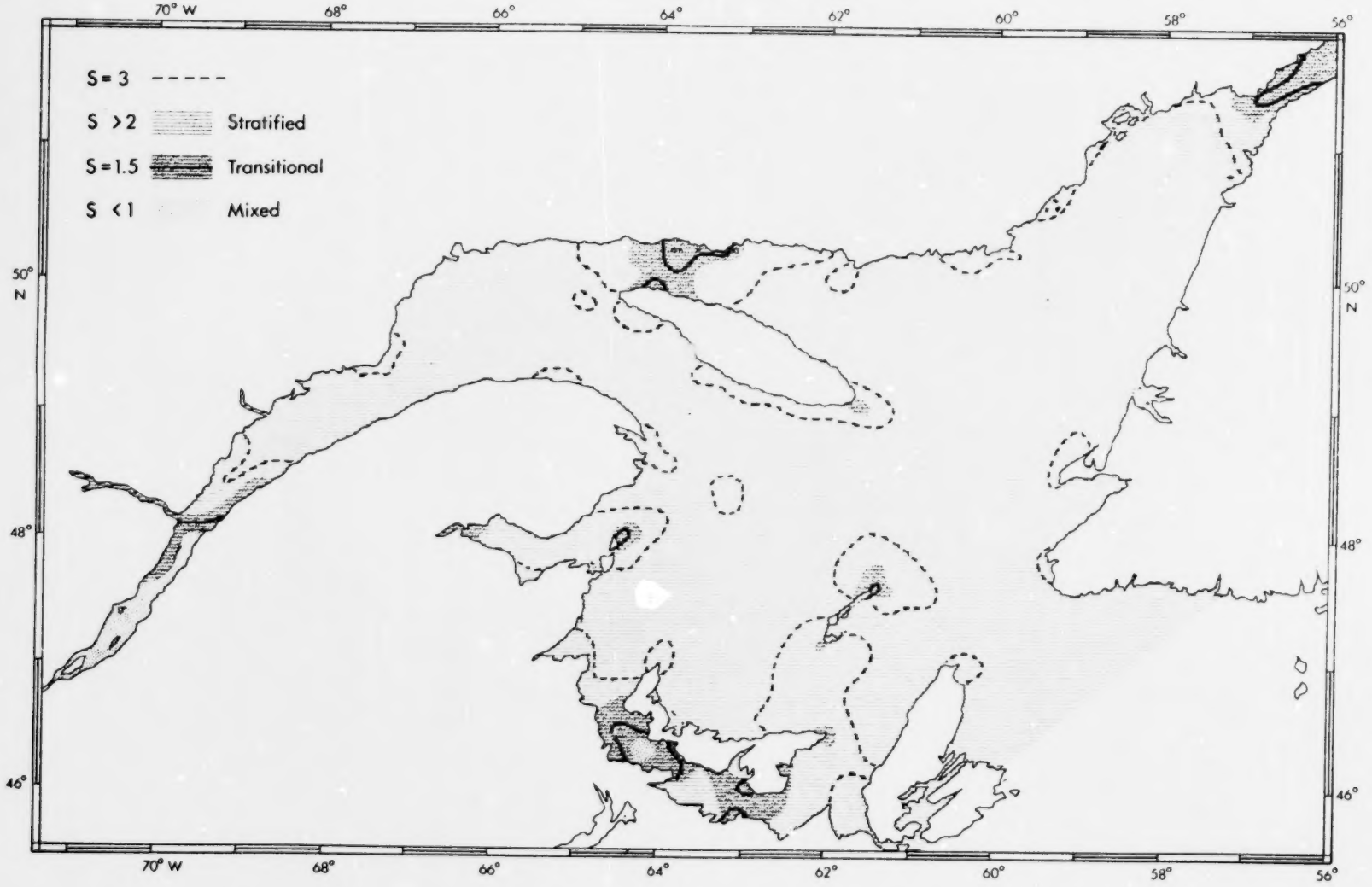


Fig. 11. Distribution of the stratification parameter in the Gulf of St. Lawrence area. Bold line identifies frontal regions (s=1.5) between stratified and well-mixed water columns. [From Pingree and Griffiths (1980).]

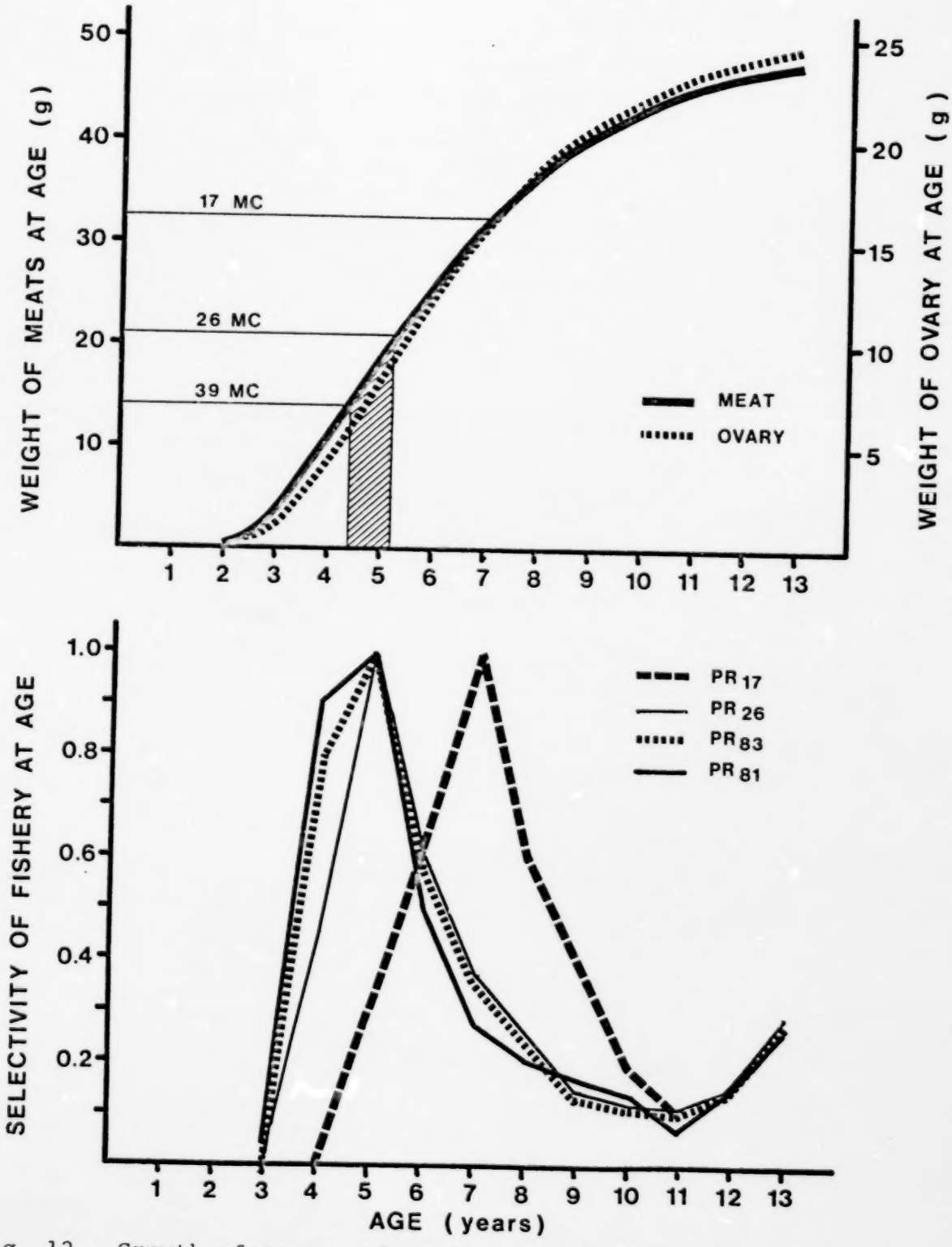


Fig. 12. Growth of meats and ovaries for Georges Bank scallops (upper figure). Selectivity-at-age patterns for actual fishing patterns on the northern edge and northeast peak of Georges Bank (PR_{81} and PR_{83}) as well as theoretical

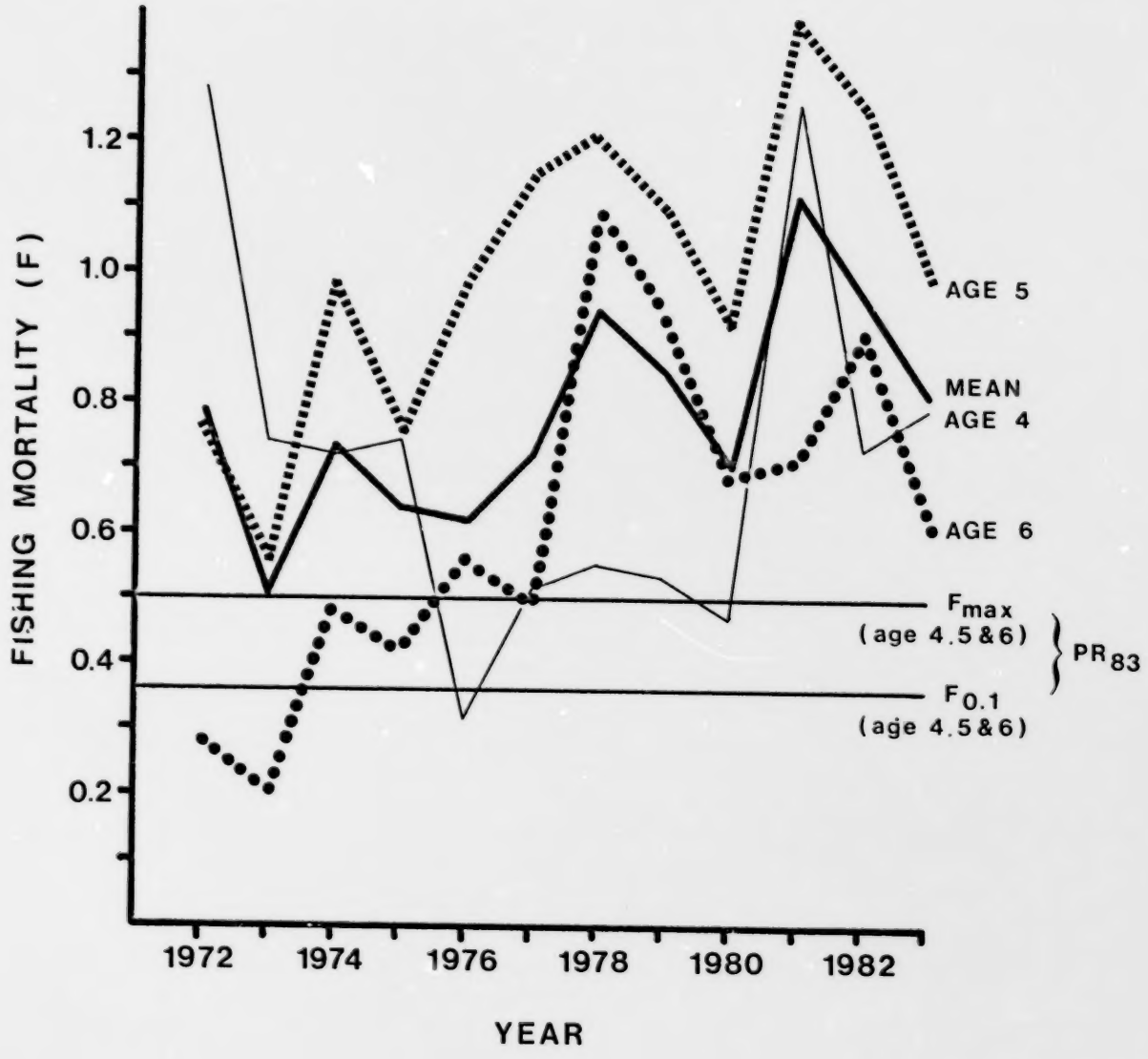


Fig. 13. Distribution of fishing mortality for the northern edge and northeast peak of Georges Bank scallops (1972 to 1983).

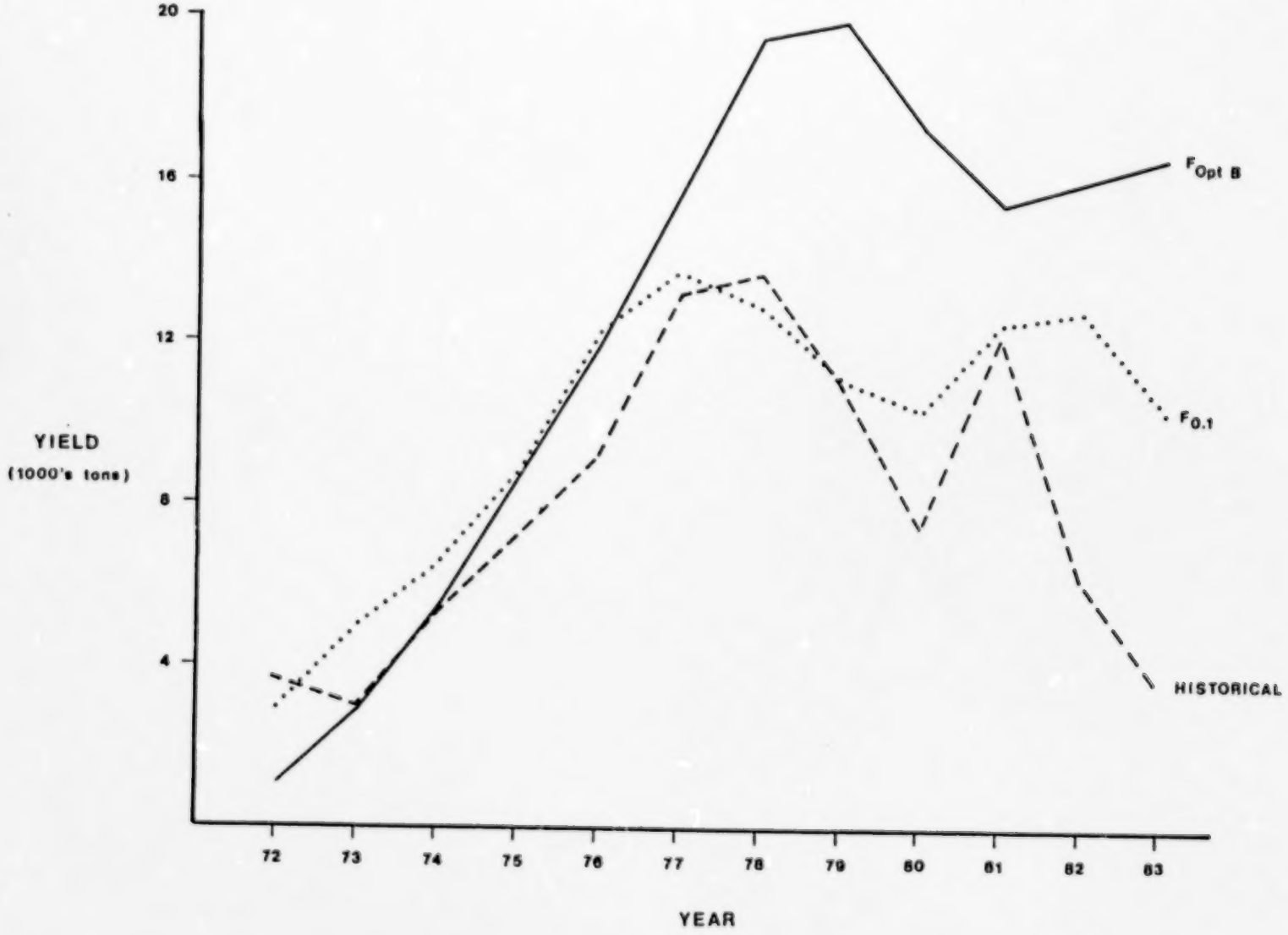


Fig. 14. Distribution of combined yield by Canada and the United States from the northern edge and northeast peak of Georges Bank from 1972 to 1983. The projected yields that could have been taken under alternate, more biologically optimal fishing strategies are also shown ($F_{0.1}$ yield and $F_{Option\ B}$ yield).

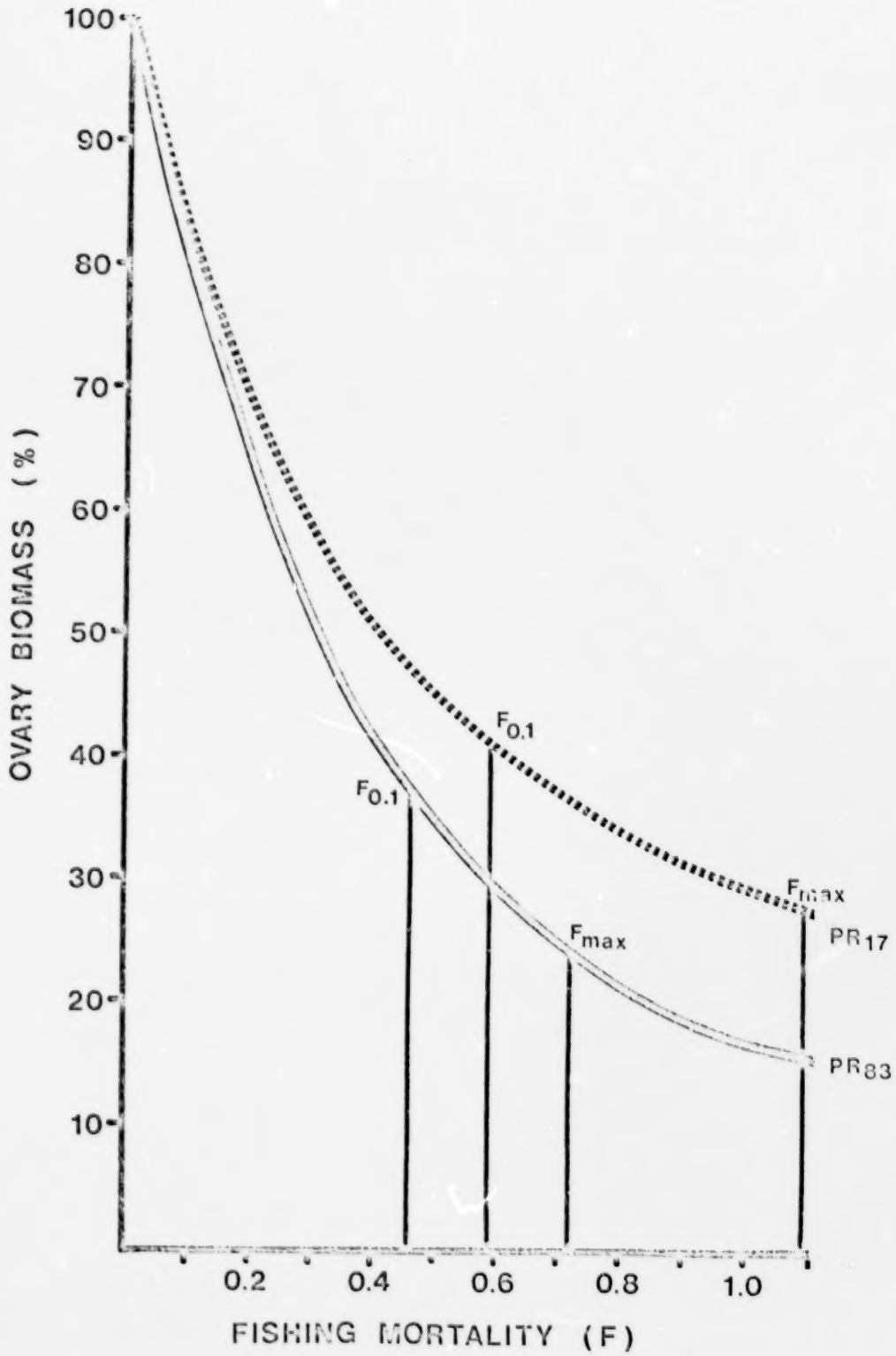


Fig. 15. Distribution of percentage of ovary biomass per recruit sustained as a function of fishing mortality, relative to the ovary biomass in the unfished situation. Two fishing patterns are shown to approximate 39 and 17 meat count situations.